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ABSTRACT

Computer graphics have been called the most exciting development in computer technology. At the University of Michigan, three kinds of graphics output equipment are now being used: symbolic printers, line plotters or drafting devices, and cathode-ray tubes (CRT). Six examples are given that demonstrate the range of graphics use at the University. (1) Computer-animated movies can be made inexpensively by any faculty member in as little as two hours, using a camera, a bi-stable storage tube of the Computek Model 400/20, and a subroutine package called Polygraphics. (2) A system of architectural graphics, called ARCH:GRAPHIC, allows the user to manipulate a set of elementary objects such as cubes, quarter circles, ochtahedrons, stick figures, and any other unit he creates. (3) A graphic presentation of fibrillation of the heart is provided by computer printouts and on the CRT. (4) Of interest to industrial designers, systems have been worked out that present free-form surfaces and time-cost schedules. (5) Geographers use computers as automatic draftsmen and pictures processors. (6) Two application systems give engineering students opportunities to experiment at the CRT instead of at the drafting board. (MF)

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COMPUTER GRAPHICS

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Collage at right illustrates the range of computer graphics at the University of Michigan. Included are a computer-drawn skull representing data from the Center for Human Growth and Development; a population map of the United States; a 15-sided geometric figure; a graphical presentation of scientific data; and frames from a computer-made movie representing the seismicity of the world—the brighter the flash, the bigger the volconic eruption.

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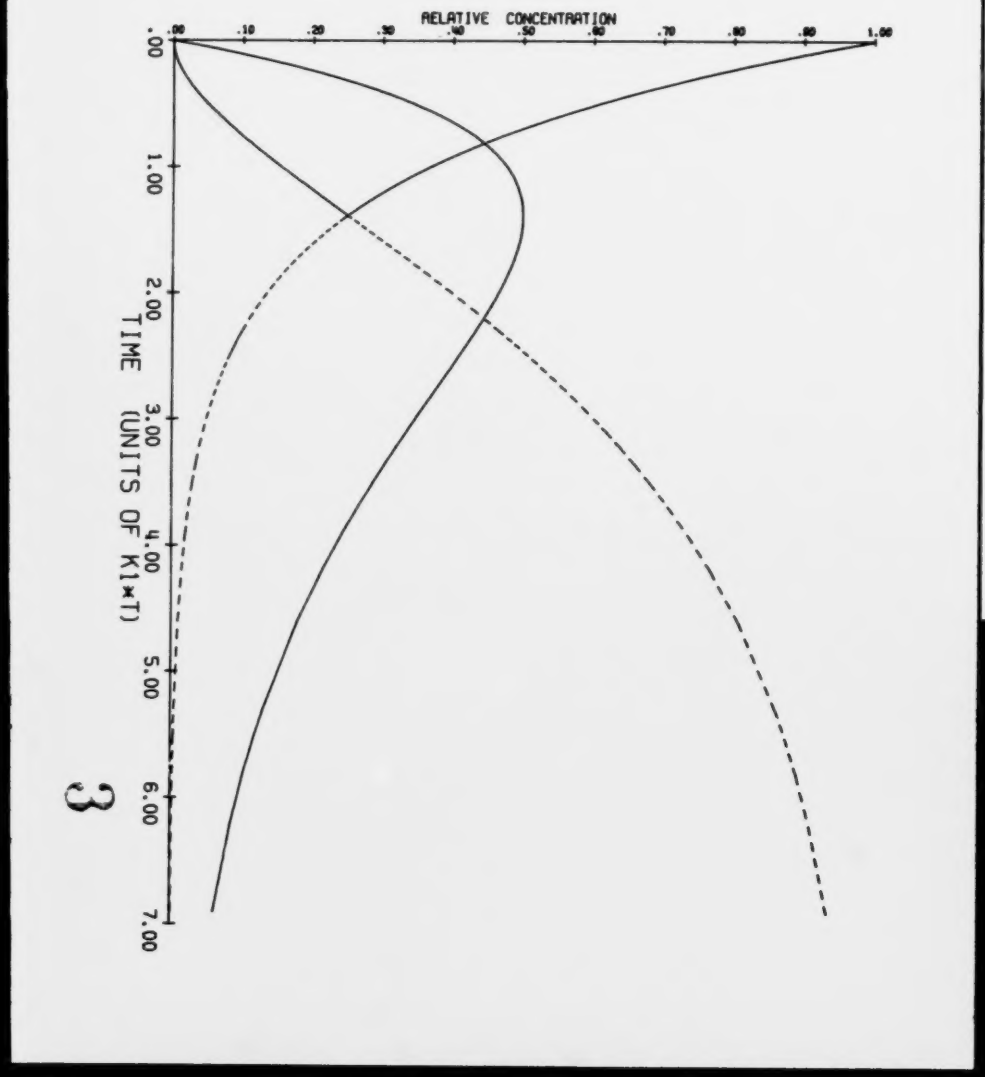
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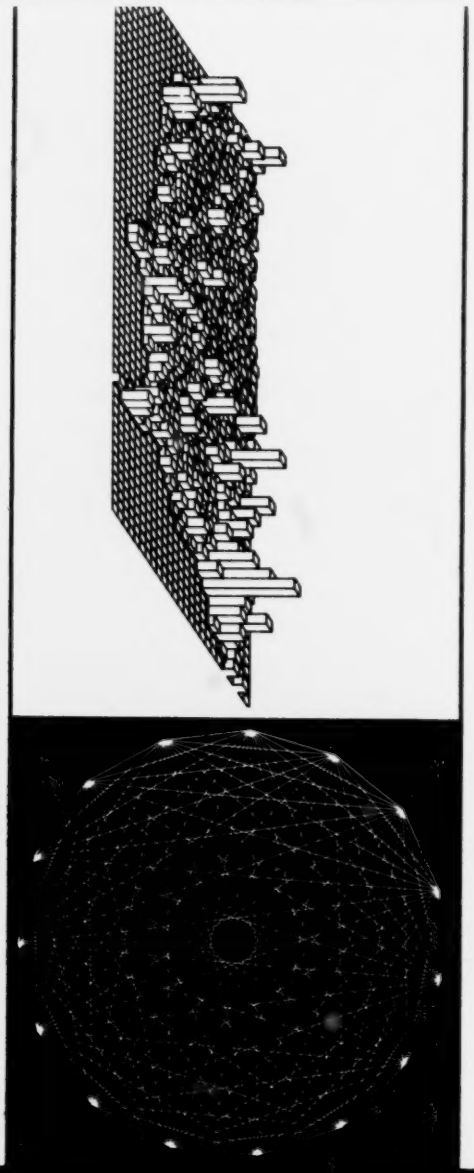
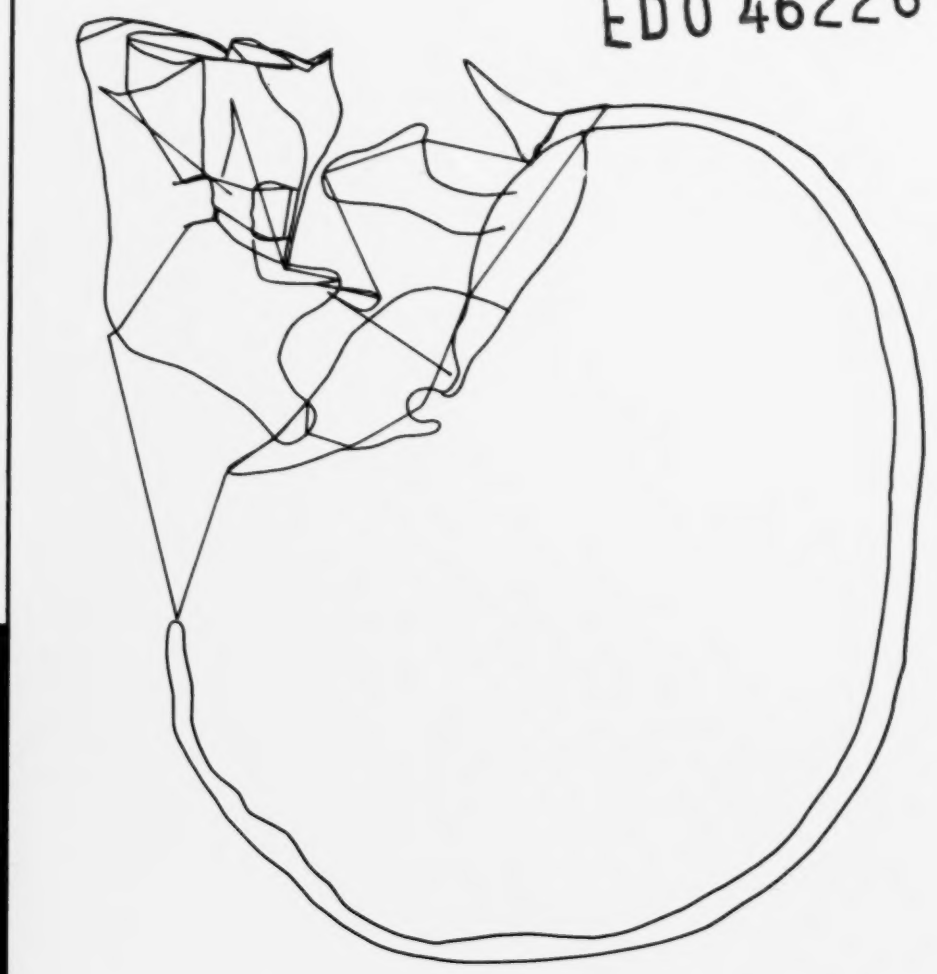
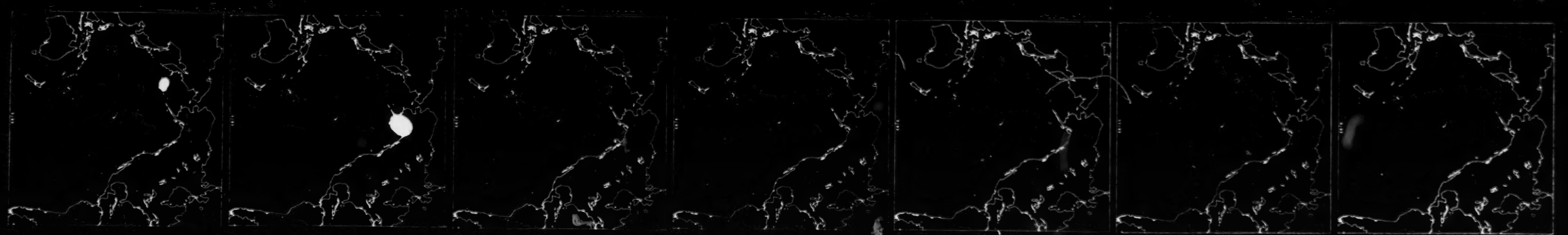






ALTHOUGH computer graphics puzzles some and frustrates all of its users at one time or another, specialists have called it the most exciting development in computer technology, and the most promising. When displays and programs click, they unite the computer's speed, memory, and reliability with man's experience, imagination, and tolerance for ambiguity. Sophisticated techniques allow users to simulate the impact of a space ship's landing on the moon; chart a patient's blood pressure, temperature, EKG, and CO_2 level on an operating room screen; sketch a picture of how a city will change if a road goes through or a shopping center goes up; communicate with severely emotionally disturbed patients; and flash movies of heat wave experiments on a classroom screen. At its best, computer graphics contradicts many of the caveats in Huxley's *Brave New World*. Instead of dehumanizing, it encourages creativity. Instead of sterilizing information, it stimulates insight. Instead of edging out human beings, it provides a congenial link between man and machine.

For nearly a decade before Ivan Sutherland developed the first graphical man-machine communication system in 1963, researchers in industry and universities hinted that graphics would offer computer users undreamed of opportunities. After Sutherland produced *Sketchpad I* at MIT's Lincoln Laboratories, however, some of the excitement faded: equipment remained extremely expensive, programming techniques and operating systems developed slowly, and research suffered from funding cutbacks. Still, an increasing number of users were becoming familiar with graphics equipment and were enticed to try the new technique in their fields. Today, computer graphics serves numerous functions in industrial, government, and university research.

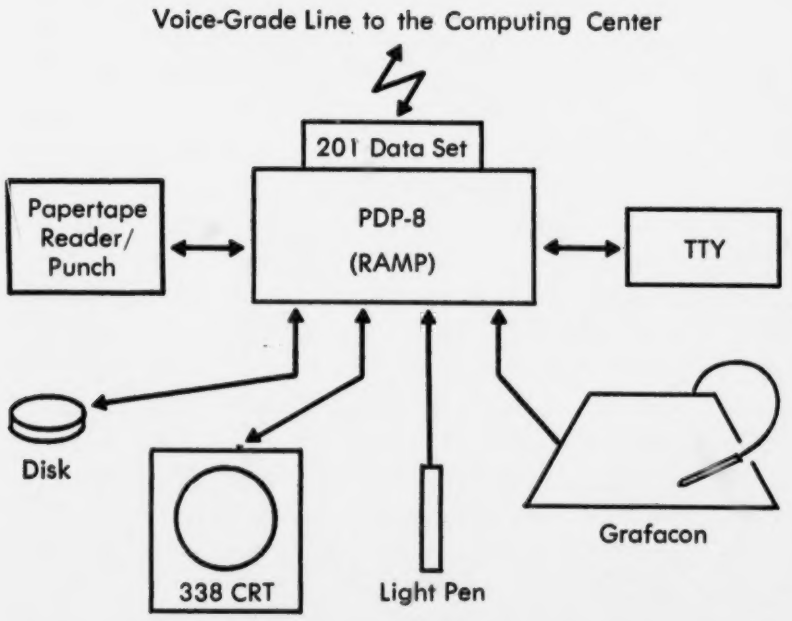
As the word implies, graphics is a way of getting information into or out of the computer in pictorial form, generally through lines and points rather than through printed cards or punched tapes. Since men think and grasp information more naturally in pictures than in binary notation, graphics draws users closer to their material and offers unaccustomed manipulability. Graphics operations can be highly interactive, as when an automotive engineer feeds fender designs into the computer by drawing on a cathode-ray tube and requests immediate pictures of how the newly designed part fits into a car assembly. Or they can be largely passive, as when a geographer programs population growth of the United States to be printed out in two-dimensional maps. Since it is much easier to get graphic information out of the computer than into it, and since most users are still more familiar with graphical output than input techniques, over three-quarters of the graphics users at the University employ the passive mode. They prepare a program to reach into a mass of complex computerized data and mold it into pictures.

The CRT system at the Ouimet Building terminal consists of a teletype, a small disk, a PDP-8 computer, a 338 display console, and, in the corner, a Calcomp plotter. The console itself includes the cathode-ray tube on which pictures are "drawn" with a light pen, the Grafacon, and a push-button box.

THREE kinds of graphics output equipment are now being used at the University: symbolic printers, line plotters or drafting devices, and cathode-ray tubes. Although tables of numbers and text produced by teletype, typewriter, or other computer-driven devices are sometimes classified as graphics because they display relationships, they lack the pictorial compression of more sophisticated techniques. Typewriter characters or arrays of arbitrary symbols, on the other hand, are used effectively to plot curves or make pictures. These sometimes suffer from the limitations and distractive qualities of the characters employed, but they offer possibilities for representing shadow and depth that other methods do not.

The second class of passive graphics and probably the most widely used includes pen-and-ink line plotters and drafting devices. Their clarity, accuracy, and complexity vary with price. Perhaps the simplest version of a plotter is a child's drafting toy called Etchasketch that costs under $2.00, but a realistic lower limit for computerized models is $5000. More complex plotters, such as the Calcomp used at the University, cost about $20,000, while fine machine-tooled versions run to a quarter of a million dollars. Models most commonly used at the University employ a computer-driven pen which describes information on a moving roll of paper to produce accurate maps, pictures, and graphs, with or without captions. Drafting devices can be programmed to record various stages in or views of a design or different aspects of a given body of information. Since a typical plotter can draw at three to ten inches per second, a user can view the product of his program within minutes instead of collecting a three-inch stack of paper six to twenty-four hours later. Among the advantages of such plotters are speed, data reduction, smoothing, reproducibility, and accuracy.

Still faster, more direct, and more dynamic is the production of pictures on the face of a cathode-ray tube (CRT) or a bi-stable storage tube. In the passive mode, these devices permit the flow and manipulation of large amounts of computer-stored information. The equipment accepts magnetic tape, punched tape, or other material prepared by a computer in digital form, then converts it into graphic images that flash on the tube like pictures on a TV screen. These images can be turned into permanent copies by still or movie cameras, video tapes, or Xerographic copiers. To cite one example, Henry Pollack, Professor of Geology, and Michael Levy, graduate student in Geology, wished to compress a mass of data on seismicity of the world into a form that would convey patterns of earthquake frequency and intensity. Data on all known earthquakes from 1961 to 1967 were recorded on magnetic tape. Pollack and Levy programmed the seismic information to flash on tape-stored maps that were continuously refreshed on the face of the CRT. They programmed information according to month, and indicated intensities of the quakes by the brightness of the electronic flashes. (The resulting time-compressed 16-mm movie, "Seismicity of the Earth 1961–1967," has



Interconnections at a remote graphics terminal plus the voice-grade transmission line connecting the terminal to the central computer are represented in the configuration. In

the photograph, James Jackson of the Electrical Engineering Department works with the SELMA graphics system on the CRT in the Systems Engineering Laboratory.

become so popular that prints are being sold at cost by the University's Seismological Observatory.) Although the complicated programming for this film was developed at the University, the film itself was produced by computer-output-to-microfilm (COM) equipment located at the General Motors Technical Center. Because the COM device, which allows CRT pictures to be imaged onto film by a lens array, is an extremely costly machine and because the seismicity film impressed many as an extremely effective teaching tool, researchers at the University have developed a similarly effective but inexpensive film-making technique based on the storage tube display. The system, which will be described more fully below, enables faculty members to compress masses of information and computation on film for classroom viewing.

The CRT and storage tube are also used for direct observation of data. Designers, engineers, architects, and others concerned with visual relationships can view designs from different angles and test aesthetic, mechanical, or performance characteristics rapidly. Physicists, chemists, and other scientists can process experimental data, describe physical systems mathematically, and observe their results on the CRT. In effect, a user can postulate a model, then ask the computer to generate several hundred frames on the tube for checking, changing, or choosing. In copy production and direct observation, passive graphics thus takes advantage of the computer's speed, memory, and ability to follow directions and produce pictures; but it does not take full advantage of man's imagination.

Interactive graphics, on the other hand, invites users to converse directly, immediately, and creatively with the computer. Using the computer in this mode differs from the familiar batch mode as a phone call differs from a letter. The user is not forced to think out a problem step-by-step from start to finish, then send the information on a batch of punched cards to the computer and await an answer. Instead, he can begin a program, watch what's happening on the CRT, decide what he wants to do next, and direct the computer either by light pen, teletype, or function keys, thus allowing a progressive investigation of a problem.

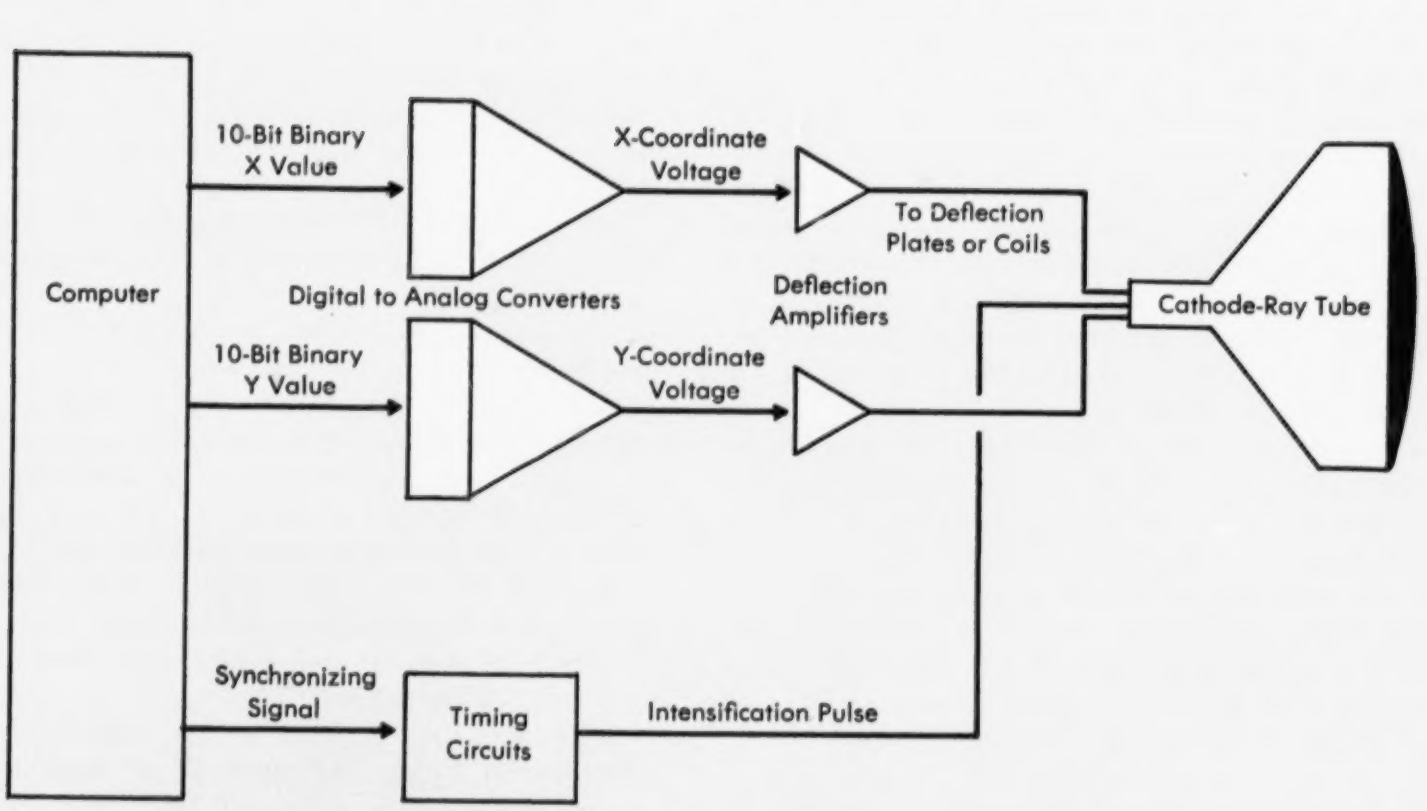
CONSIDER Dr. Michael Andrews, a fictitious history professor who comes to the graphics terminal on main campus to work with computerized data on population growth, wars, war durations, and war casualties. Dr. Andrews has had some experience with the Michigan Terminal System (the operating system for the central computing facility) and has learned to use a basic command language and to program his data by Quikplot for rapid manipulation. He phones the Computing Center and signs on with his user number and ID password. He then teletypes a command that gives his program name, thus initiating the retrieval of information for display on the CRT. As the Computing Center sends information, yellow lights flash indicating that impulses are being received on the small computer attached to the CRT. Now text, points, and lines begin to light the face of the tube. The text contains such options as PLOT, PRINT, DISPLAY, CORRELATE, MOVE, ROTATE, START, ESCAPE. Andrews moves the light pen to START, then indicates a starting point on the screen and pushes a key that calls up world population growth data. On the screen flashes the request, PRESENT TIME RANGE. Andrews calls for the last century. He wishes to explore the relationships between population growth and the frequency, duration, and magnitude of wars between 1870 and 1970. He has recently used the computer to calculate and print tables of numbers on these data by decade, but finds that while the figures are probably more accurate in decimal places than what the CRT will produce, they give him no insight into the problem and describe no relationships. A white line climbs across the screen, indicating an undulating pattern of population growth by decade. Andrews gestures with the light pen to raise the population curve and display below it a curve of war frequency. He continues to operate with a combination of light pen, function keys, and teletype, displaying the information for one decade at a time, then by country, then by region. When he produces a picture that has meaning to him, or gives him an idea for future research, he directs the computer to store it in binary form in the memory. When he wishes to change the kind of questions he is asking and follow a new tack, he moves the light pen to ESCAPE.

During this session at the terminal, Dr. Andrews has been "on line" to the central computer and has been receiving information, manipulating it, and occasionally sending information to the memory for storage. To do this, he has made extensive use of computer hardware (machinery related to memory, input-output, and control) and software (machine programs and data). He made contact with the central computer through a combination of phone line, light pen, functions keys, teletype, and cathode-ray tube attached to a small local computer.

The cathode-ray tube displays a grid, a system of coordinate points, 1024 rows by 1024 columns (or up to four times that number in some models). To specify a point on this 1024 x 1024 array, each x and y value transmitted by the computer contains ten binary digits or "bits" ($2^{10} = 1024$). Thus when Dr. Andrews called up a curve of population growth between 1870 and 1970, the computer retrieved information that had been stored in digital form on cards and tape and presented it to analog circuits that traced lines and characters on the screen, presenting the stored data in light-picture form. He manipulated these data with a variety of gadgets, the most intriguing of which was the light pen. Although the pen gives the illusion of drawing, or depositing lines on a surface, it is actually detecting points already present on the tube. The light pen,

of course, is not really a pen at all but a fiber optics bundle, open at the end pointing at the scope and wired from the other end to a photomultiplier tube. The information conducted through the pen tells the computer which object should be changed or which course of action followed. Thus Andrews had only to point at the text on the screen, the word PLOT, for instance, to communicate with the computer. Other tools Andrews used included the function keys, which allowed him to call up the subroutines he wished for ordering the material filed in the computer, and the teletype, which he used to send the storage addresses or memory locations of his data to the central computer for retrieval and presentation on the CRT. One important piece of input equipment Andrews did not use was the drawing tablet or Grafacon. This is actually a plastic-covered, backlighted grid with the same 1024 x 1024 system as the tube. Each line or wire carries a separate code, and the intersection of these wires is a point with a specific coordinate value and corresponding impulse. To communicate with the computer through the tablet, a user employs a stylus that is connected with the system as the light pen is. Information a user draws on the tablet, such as a tracing of jawbone X-rays for anthropological studies, may either be stored in the memory on tapes or cards, printed out on the teletype or plotter, or flashed on the CRT for correcting, smoothing, or analysis.

There are two systems for presenting material on the face of the CRT: calligraphic displays and raster displays. The



Equipment for computer displays consists of a digital computer, which specifies the point-by-point coordinates of the desired display, together with circuits that convert the digital output into analog form for deflecting the electron beam in a cathode-ray tube. If the values of x *and* y *are each specified by 10 binary digits (0's and 1's), the electron beam can be directed to any point in an array consisting of 1024 lines (the* y *axis) and 1024 points per line (the* x *axis). With only the circuits shown here, the image on the screen would have to be built up from discrete points. Some modern displays include analog function generators to sweep the electron beam in a continuous fashion to generate smooth lines, numbers, letters of the alphabet, and special symbols.*

calligraphic display that Andrews used painted pictures on the CRT in the sequence specified by the computer. The electron beam simply traced the individual lines or characters to make up the picture. Although calligraphic machinery is relatively simple and efficient, calligraphy remains a costly way to draw pictures since machine parts are not mass-produced. Raster displays, on the other hand, make pictures the same way TV sets do: the image is painted as the electron beam moves across the screen in a fixed sequence, usually left to right, top to bottom. Thus information for a raster display must be sorted left to right, top to bottom. Although this requires an extra programming step, the equipment needed to produce raster displays is the same as that used in home television sets, making rasters relatively economical.

In both types of display, analog circuits connect the computer to the display tube by means of a data processor, programmed to convert binary information to elementary driving signals. The display processor, which accounts for more than half the cost of a system, interprets different forms of information from the memory in terms of the desired pictorial presentation. Like other computers, display processors require a great deal of programming or software to make them useful.

Three kinds of software made Andrew's use of the CRT possible: (1) a generalized monitoring program that schedules, presents, and files information for the entire computer time-sharing system; (2) Andrew's data base representing selected facts about population and wars; (3) a computer graphics program that generates impulses in response to requests from Andrew's light pen, keyboard, and teletype. Since the format of information in the data base is not usually suitable for direct use by the display processor, another program that allows the display processor to extract the "picture" from the data is generally required. The data in this form are called the display file program. If, for example, Andrews points to an object of interest on the screen, the light pen produces a brief impulse telling the computer which object in the display file is to be changed. The data processor then interprets the signal and makes the changes in the data base that will instantly be reflected in the picture at the graphics display terminal.

OF the hundred-plus remote terminals currently located around the Ann Arbor, Dearborn, and Flint campuses, terminals with CRT facilities are the newest and least common. One of the most widely used CRT terminals was installed on the second floor of the Ouimet Building, 611 Church Street, in conjunction with the ConComp Project described below. In addition to the CRT, with its direct telephone connection to the Computing Center, this terminal contains a small computer, a Calcomp plotter, and a Grafacon. The terminal may be used by anyone with an account number, a valid Computing Center user number, and some training in its use. When the Computing Center moves to its new facility on North Campus early in 1971, this terminal will be transferred to the building at 1000 N. University that presently houses the central computer. Another impressive graphics terminal acquired under ConComp is located on the second floor of the East Engineering Building. Although it has been used largely for work in electronic circuits and queueing systems, it also is now available for general use. The third ConComp-related display terminal on main campus is being used by the Logic of Computers Group in its analysis of self-organizing systems. The display terminal at the Gas Dynamics Laboratory on North Campus differs from those on main campus because it employs a relatively inexpensive bi-stable storage tube as the medium of display. Unlike the ordinary CRT, on which the display is refreshed at least thirty times per second, causing a perceptible flicker when many lines are drawn, the storage tube has a special type of phosphor that retains a high resolution and bright, flicker-free display without refreshing for up to half an hour. Thus it is extremely useful for the production of computer-animated films. There are nine storage tube terminals at the University at present, and a projected engineering graphics laboratory calls for four more. Many other terminals with only computer-driven printers and plotters bring graphic information to laboratories and classrooms throughout the University.

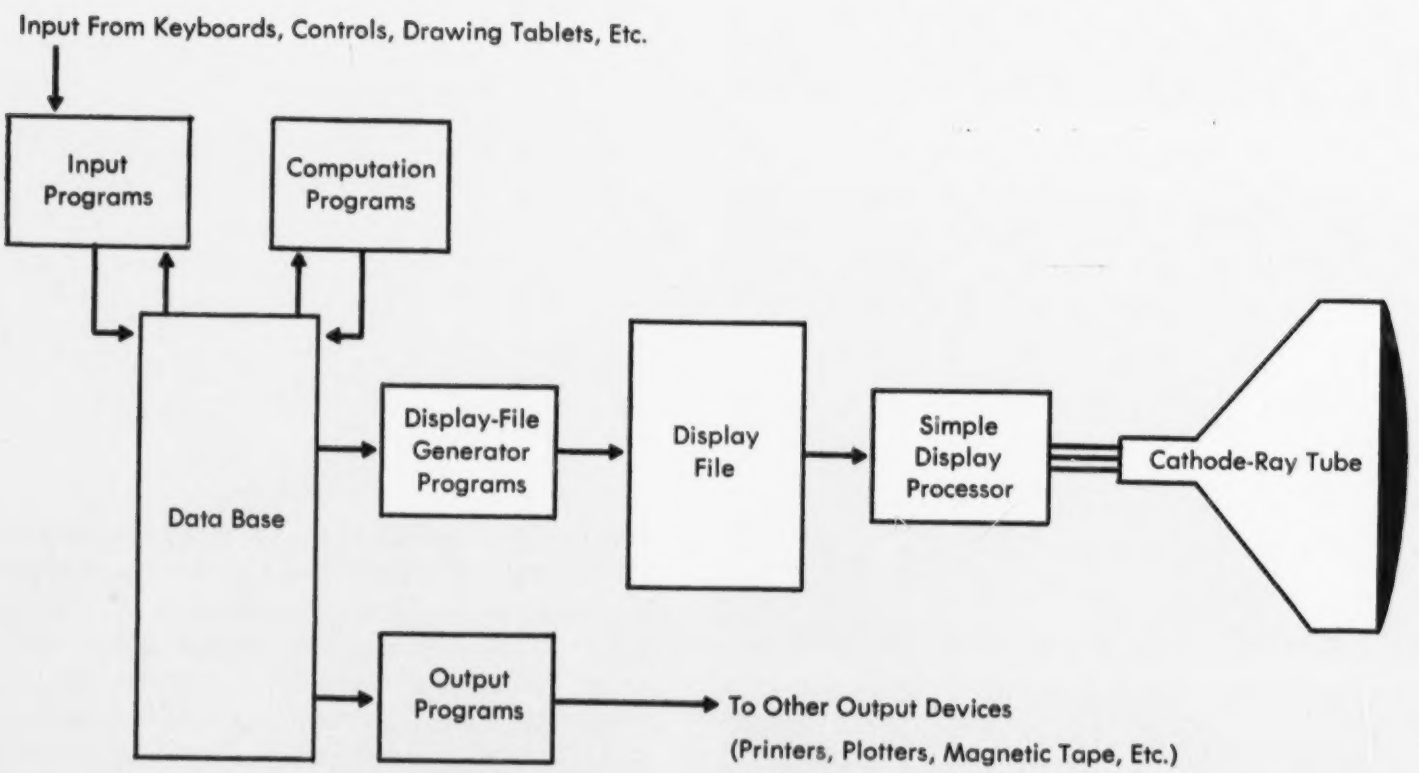
Operating from CRT terminals is not always an unmitigated pleasure, and sometimes it can be as nerve-racking as driving on the Detroit expressway at 4:30 p.m. This is partly due to changes being incorporated into the system and partly due to difficulties associated with processing display information within the Center's time-sharing system. Delays that stem from translating computer information into voice-grade transmission for subsequent pictorial presentation also add a touch of frustration. In general, however, such difficulties have challenged the staff at the Computing Center to make consistent improvements. Terminal connections are now much smoother than they were two or three years ago, and users and staff members anticipate continued refinement.

Of a more general nature are problems associated with the medium of the CRT itself. These include the limits placed on the number of lines the CRT can display without flicker; the windowing problem in which symbols that overlap an edge of the screen reappear at the opposite edge (positions at the right of the screen appear at the left edge; those just above the top edge roll on at the bottom); the problems associated with manipulating the data base fast enough to take full advantage of high-speed displays; and the solution of the hidden line problem, that is, permitting the computer to compute what parts of an object are visible from a certain angle and what parts are not, and thus show or turn objects to replicate reality. Solutions to technical

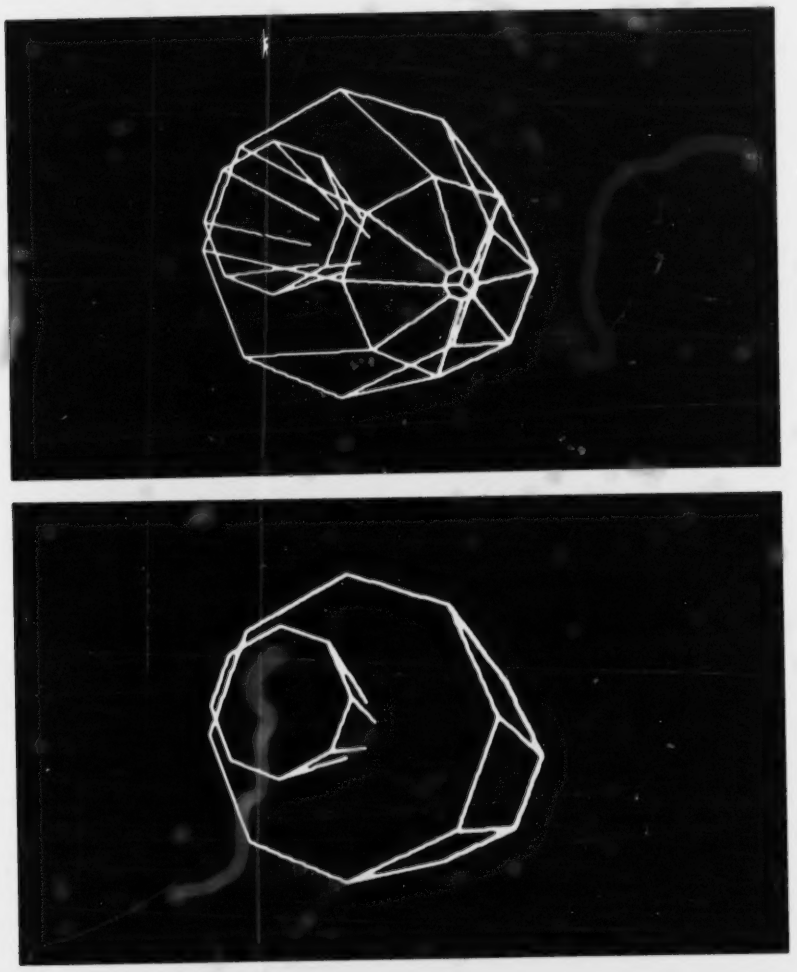
problems of this kind are being worked out by experts at laboratories and universities throughout the world.

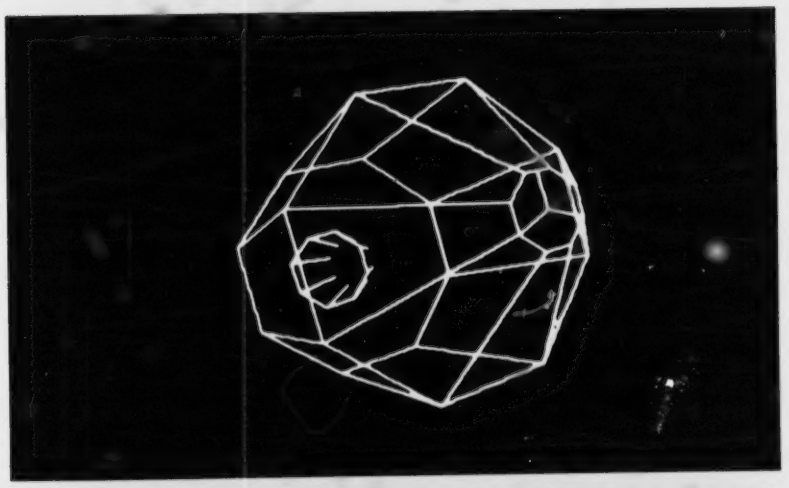
AT the University of Michigan, researchers in computer graphics are developing equipment and programs to make the computer more accessible and useful. Franklin H. Westervelt, Professor of Mechanical Engineering and Associate Director of the Computing Center, points out that just as most people drive cars effectively without knowing the mechanics of an internal combustion engine, most people should be able to take advantage of Computing Center facilities with a minimal background in the technicalities of computing. The three-year ConComp Project, directed by Westervelt and sponsored by the Department of Defense, was devoted to research in the conversational use of computers. This project furnished much of the CRT graphics equipment at the University and enhanced the interactive aspects of the Michigan Terminal System through innovations like the Data Concentrator. The ConComp staff built Data Concentrator hardware around a DEC PDP-8 computer, and attached this small computer to the central computer to expedite communications with remote keyboard and graphics terminals. For the display user, Dr. Alfred B. Cocanower of the ConComp project devised a package of display file routines that minimizes the user's need to know the intricacies of graphics display hardware.

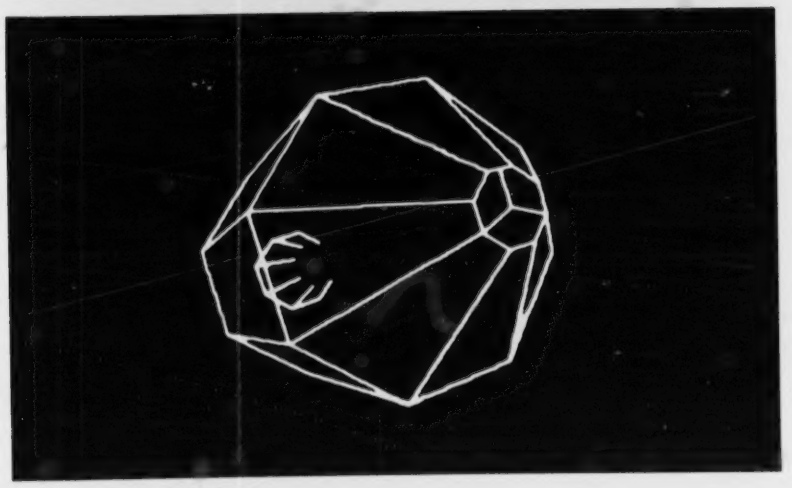
Another research project aimed at making the computer more useful to more people is the Data Acquisition-Graphics (DAG) system, developed by Donald E. Geister



Program structure for computer displays typically takes the form shown here. Information about objects is stored in the data base. Information about the appearance of objects is stored in the display file. The actual appearance of the objects is specified by programs in the display file generator. These programs perform geometric operations and expand the definitions of objects. Advanced display processors eliminate the display file and display file generator by providing more powerful computation and selection functions. This simplifies programming by eliminating elaborate cross-references between the data base and the display file.







and Richard L. Phillips of the Aerospace Engineering Department, and sponsored by the National Science Foundation. DAG provides on-line low-cost graphical data reduction for undergraduate engineering laboratories. Its aim is to increase interest in experiments and improve understanding of basic phenomena by avoiding time lapses that often result from complicated data gathering and reduction procedures. Geister and Phillips designed and built the data-acquisition system, used a bi-stable storage tube as the display device in a computer terminal, along with the necessary control and display electronics, and linked the terminal by telephone to the central computer. Transducers in the laboratory measure pressures, temperature, force, and other data during the experiment, and instantly relay these data to the computer for calculating. The results are then displayed on the tube in graphical form. Students may Xerox output and incorporate the data in laboratory reports. Thus the ConComp and DAG projects, plus others such as film-making programs described below, are attempts to develop equipment and systems that will allow any professor or student to use graphics effectively.

About fifteen percent of Computing Center users, or over a thousand people at the University, now use graphics. Some simply plot output material graphically, while others use the CRT interactively to solve complicated design

Hidden lines are the edges of an object obstructed from view because they are behind the object, and hidden line removal has been a persistent problem in CRT computer graphics. To illustrate real-time partial hidden line removal, James Jackson and James Blinn, graduate students in Electrical Engineering, prepared an Apollo docking simulation program. The program considers the user to be inside the lunar module (LEM) and to be able to control in limited fashion both his own spacecraft and the common service module (CSM). Here, two views of the CSM are shown as they would appear through a window in the LEM. Each view is shown both with all lines drawn and with hidden lines partially removed.

problems. Among the first users were the engineers, physicists, and applied mathematicians who adapted the facilities for use at the University. Since then, users have "discovered" graphics in a variety of outlandish ways. A doctor in the Medical School who had never used the Computing Center went on a camping trip with a friend who worked at the Center. They discussed ways of exploring a basic problem in heart research through graphic displays; the doctor has used graphics ever since, and now teaches two courses related to the medical uses of computers. Most faculty and students, however, come to graphics by seeing a presentation and mulling over how they might apply the techniques to their work. Although a few users have only a rudimentary knowledge of computer operations, most have at least an acquaintance with basic technical details.

How would a faculty member or student who thought computer graphics appropriate to his work begin? He would probably take one of the non-credit evening lecture series offered by the Computing Center and then discuss his interest with someone at the Center. Together, they would decide whether one of the prepared programs could handle the professor's material appropriately, or whether he would have to learn a computer language such as FORTRAN or PL/I to write a program for his material. When Dr. Pollack made his seismology film, for example, he was able to use a map program originally developed by Dr. Waldo Tobler of the Geography Department. But when Harold Borkin and Dale Bryant of the Architectural Research Laboratory wanted a program that would allow them to walk through an imaginary city, they started from scratch: they learned FORTRAN IV and wrote their own statements. A professor or student usually finds it practical to know one of the relatively simple program languages and to take the regularly scheduled course, IE 478 Computer Graphics, which includes instruction in the use of CRT graphics equipment. In addition, many prefer to know the command language of MTS, which allows the users to communicate with the central computer. As he tries the command language, a user sitting at the CRT rapidly learns how the computer responds. Direct use of the terminal facilities thus enables him to learn from his own errors, to reformulate questions with precision, and to get more comprehensible, useful answers. "Once he has reached the point of sitting at the tube," said Franklin Westervelt, "the computer is no longer an object of fear but part of his kit of tools."

The following pages illustrate graphics projects connected with architecture, engineering, geography, geology, and medicine. These six examples demonstrate the range of graphics uses at the University and show how graphics offers congenial link between computers and people.

WITH $40 AND A LITTLE FORTRAN – Computer-Animated Movies

Any faculty member may now program, preview, and produce inexpensive computer-animated films in as little as two hours. He may use these one-to-three-minute (1000-to-3000 frame) films to supplement his lectures, present elaborate data in a compact way, or animate concepts that are hard to get across by talk or text. Although computer-aided film-making was first discussed some seven years ago by K. C. Knowlton of Bell Laboratories, and some costly computer-output-to-microfilm devices are now in use, only recently has film-making become inexpensive enough for classroom use. Under an initial seed grant from the University's Office of Research Administration and a subsequent grant from the National Science Foundation, Richard L. Phillips, Associate Professor of Aerospace Engineering, developed a system for the production of computer-animated movies from a remote storage tube terminal.

To make the films, a camera photographs static displays one frame at a time. The displays appear on a bi-stable storage tube of the Computek Model 400/20, located on North Campus. The tube has excellent resolution and can retain complex flicker-free frames up to half an hour. What appears on the screen are data programmed by the instructor, and calculated and relayed through the Computing Center to the terminal. When a complete frame is drawn on the tube, the last character transmitted triggers the camera to record the frame. After exposure, the frame is advanced, a screen-erase signal is sent to the display, and another frame begins. Although the storage tube does not employ a light pen as a mode of control, films can be added to or edited interactively through control buttons at the terminal, joystick operations, or a Grafacon.

A subroutine package called Polygraphics, developed at the Polytechnic Institute of Brooklyn in 1968 and adapted to Computek by Phillips, allows users to employ cinematic techniques such as zooming, panning, scaling, and merging of scenes. A user may also view a single frame to check for composition and errors, review a few frames, retrieve and display past frames, and preview the whole film.

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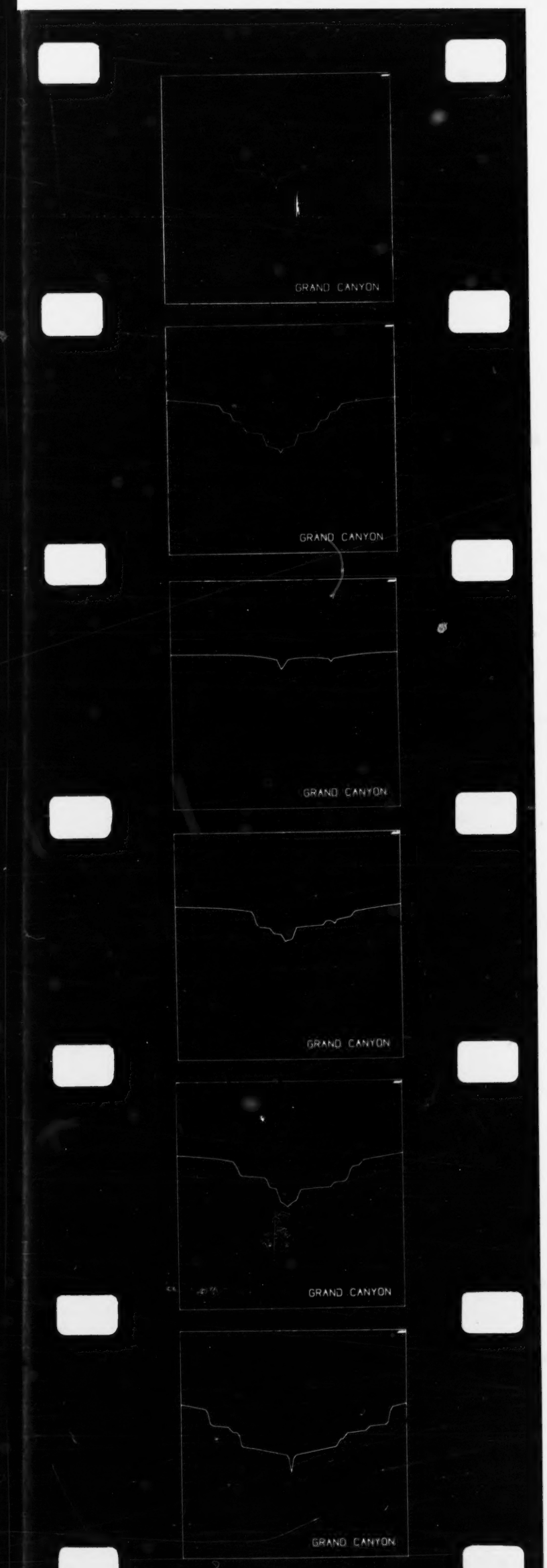


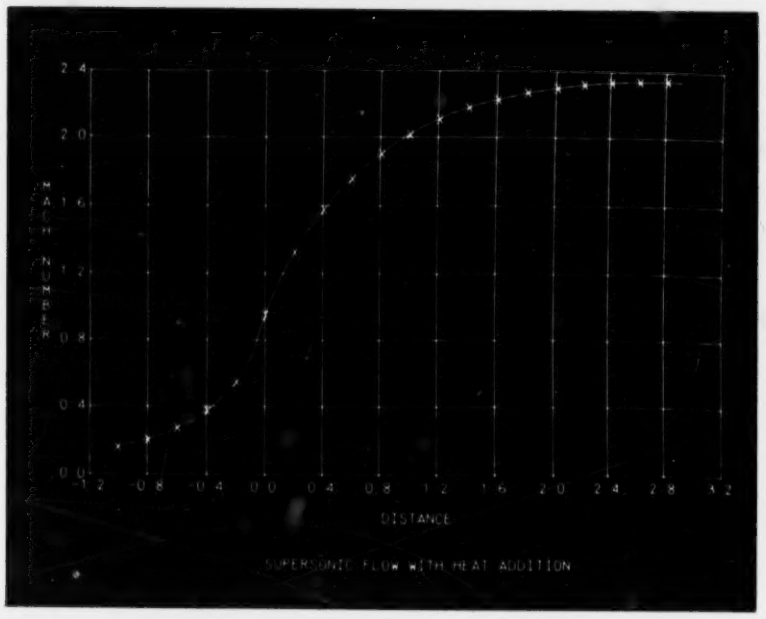
Computek Model 400/20 display terminal with a bi-stable storage tube produces clear, flicker-free pictures and has been used for laboratory data reduction and for making computer-animated films. Left: *This film strip was produced by Dr. Henry Pollack and Michael Levy of the Geology Department to illustrate the general process of the erosion of the Grand Canyon. Built into the models were technical data on soil structure and rate of erosion in relation to layering of substrata. Pollack extrapolated a one-stream and a two-stream model for a few million years to see which result most nearly approximated the present Canyon. The upper frames, based on the one-stream theory, do not represent the way the Canyon developed; the lower frames, based on the two-stream theory, illustrate the phenomenon of stream capture and show a resemblance to the actual appearance of the Canyon.* Right: *Graphical representation of laboratory data is shown on a Computek storage tube. As the program of supersonic flow with heat addition progresses, points are computed and plotted, added to, and finally drawn on the screen to indicate Mach number variations throughout a DeLaval nozzle. If something is obviously wrong with the data, it will show up more quickly on the screen than it would in tabulated printout form.* Far right: *Computer-animated films allow faculty to demonstrate theoretical phenomena in class. The frames shown here are from a film prepared by Dr. Richard Phillips to show the effect of a thermal pulse on a column of gas. The temperature adjustment causes waves of temperature to propagate inward as the temperature of the wall is raised. Shown in two speeds, the heat looks like a gently pulsating line that moves from the edge upward to the center.*

Computer-Animated Movies *(continued)*

The 16-mm film can be developed in the usual way and then shown through a 16-mm projector. One of Phillips's aims, however, is to encourage regular use of films in courses, and to do this he now produces films to be used in Technicolor Super-8 endless loop cartridges. This final step required that the film be sent away for optical printing from 16-mm to Super-8, then loaded in special lubricated cartridges. Approximately 60 feet of Super-8 can be accommodated in these cartridges, giving a viewing time of up to four minutes. The films are finally shown on a rear screen projector which has a bright 16 x 20 inch screen and looks like a classroom TV.

Costs are difficult to pin down, but assuming that the programming is not counted in the cost (students provide excellent programming service at little or no cost), expenses begin at the first terminal sign-on. Terminal hookup charges are $2.50, and Phillips has produced a 2000-frame film using less than $20 of computer time. On-site developing is $2.00 at most, so the finished 16-mm film costs about $25. Conversion to Super-8 brings the cost of a two-minute film to about $40.

Among the fascinating possibilities this process offers are color filming and Xerox copying. While it is impossible to make a color film directly from the storage tube, Phillips can transfer the screen image through a color program to a monitor screen that looks like a color TV set. Users can make a black and white copy of any frame for laboratory reports or other uses. At this time, Phillips and his associates are continuing to simplify the operation so that anyone can use the system with ease.

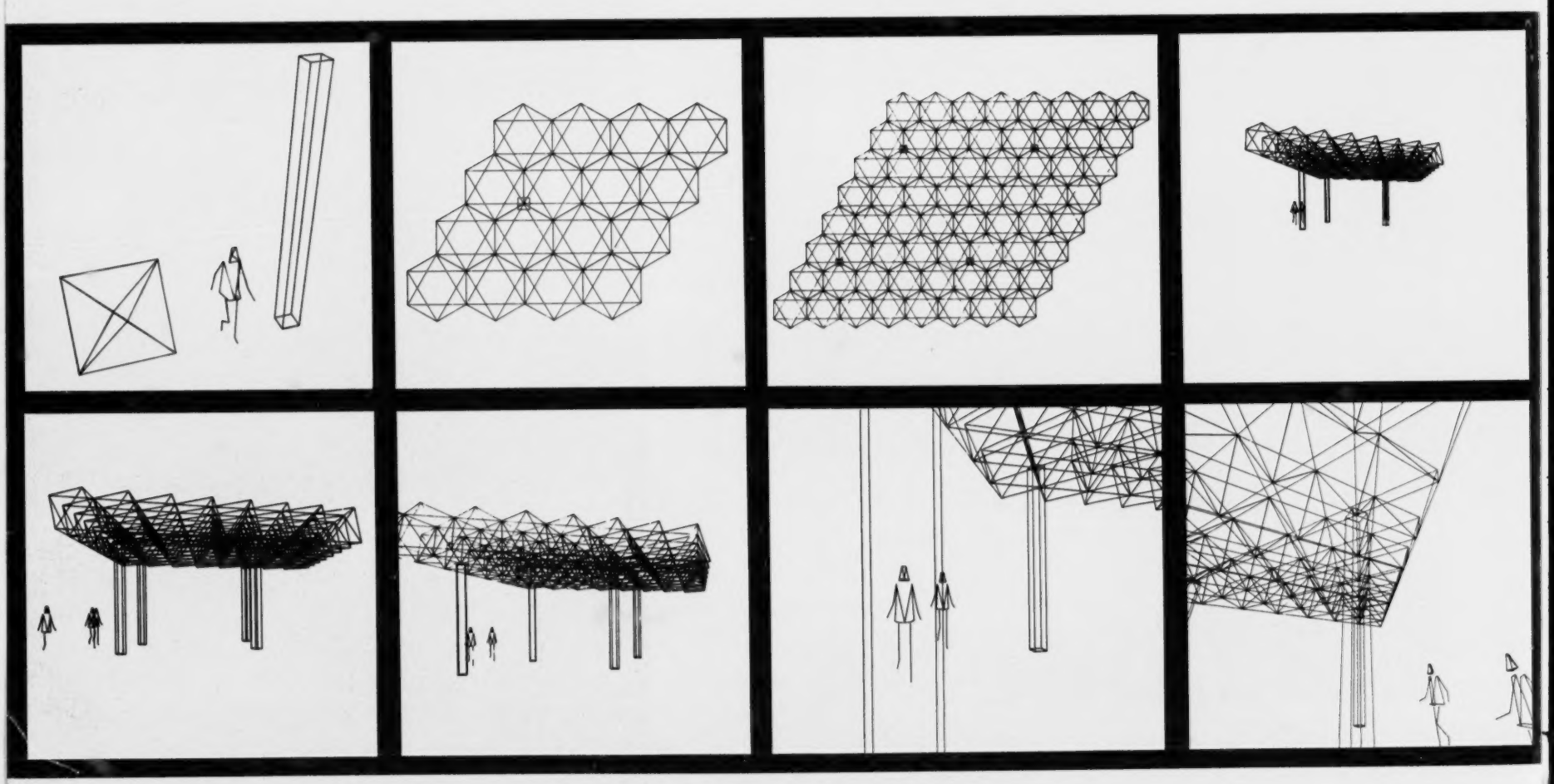


PERSPECTIVES IN ARCHITECTURE AND DESIGN

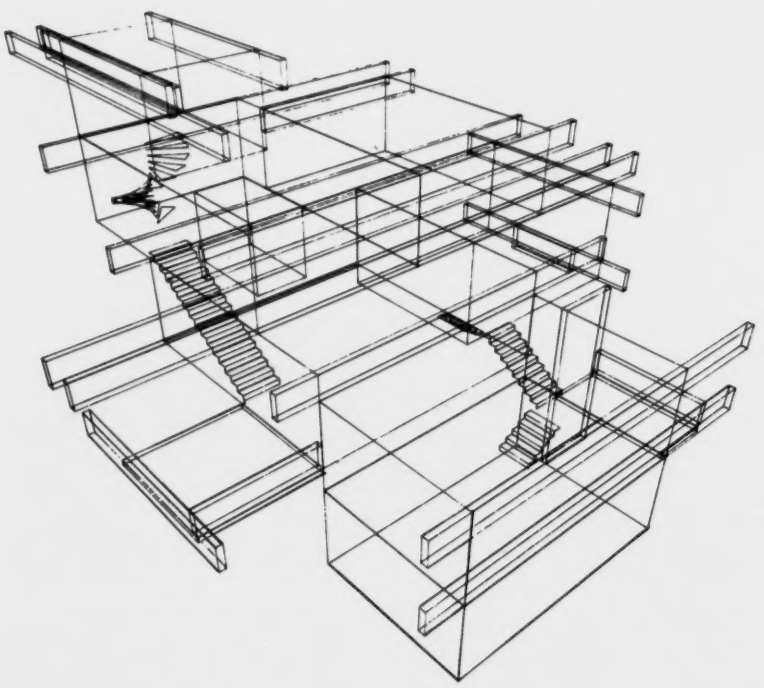
Harold Borkin, Associate Professor of Architecture, and Dale Bryant, Instructor and graduate student, developed a system of architectural graphics under grants from the University's Rackham School of Graduate Studies and the Department of Architecture. The system, called ARCH: GRAPHIC, is used in research and instruction.

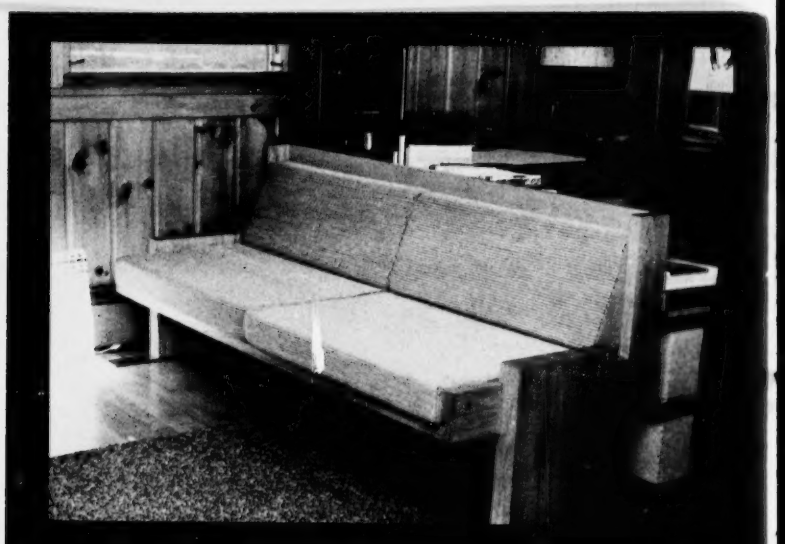
ARCH:GRAPHIC allows a user at any University terminal to manipulate a set of elementary objects such as cubes, quarter circles, octahedrons, stick figures, and any other unit he creates. The user can pile up these shapes to form larger objects, draw buildings, or design whole cities on the face of the CRT or with a pen and paper plotter. Because the program permits display of an object in relation to latitude, season, day, and hour, the architect can see his designs in time as well as space. The graphic display can show where shadows fall, and how appearances change with the months. It would be possible, for example, to call up a solar view of a building as it would look from above at noon on New Year's Day. In addition, the CRT allows architectural researchers to show hidden spaces and interior views of a building to plan electrical, water, and temperature-control systems; to organize buildings in relation to their surroundings; and to present buildings as they will look to people walking through or between them. It is much faster to see a dozen computer-produced views of what a building or object would look like from all sides than to draw them by hand, and much less liable to error. Dale Bryant recently used this program to design the couch that is now in his living room. Although ARCH:GRAPHIC required a good deal of formulation and is fairly elaborate, it allows maximum freedom of manipulation and requires relatively little computer sophistication of the user.

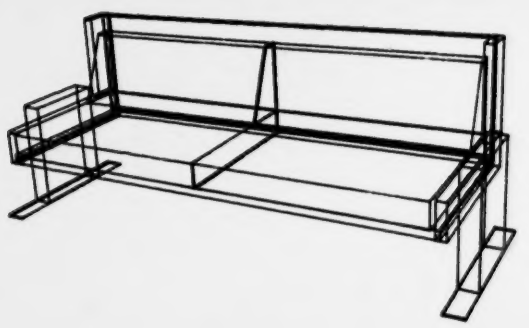
One of Borkin's and Bryant's main purposes, in fact, was to write a program that would be easy for students to learn from and use. ARCH:GRAPHIC allows undergraduates and graduate students enrolled in the two architectural computing courses, plus students in landscape architecture, urban design, and those connected with the Environmental Simulation Center, to do classwork, experiments, and even write site proposals. In one project, a group of students was asked to place two hundred building units of certain dimensions on a piece of property. They fed this problem into the computer, along with rules they devised to govern the plan, i.e., that no building rise over ten stories, and that no two buildings be less than 20′ apart. The computer produced a variety of layouts, and the students chose, adapted, and submitted the one they found most pleasing. Students also experiment with house design and art work through this program. A recent Master of Fine Arts student, for example, showed a variety of computer drawings and forms at a recent exhibit. According to Frank Westervelt, Associate Director of the Computing Center, students,

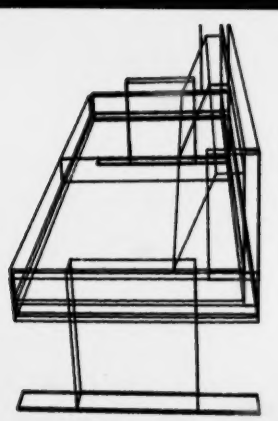


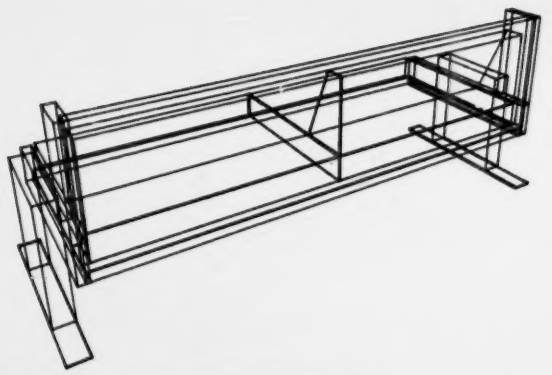
artists, and architects are encouraged to make creative use of the computer by rotating, shrinking, overlaying, stretching, and repeating parts of drawings. "This allows artists to add their discrimination, judgment, and creativity to the thing the computer does best," said Westervelt, "follow rules." Although relatively few artists and architects in the country use computers professionally as yet, programs like ARCH:GRAPHIC make the computer a more approachable tool for those who will.



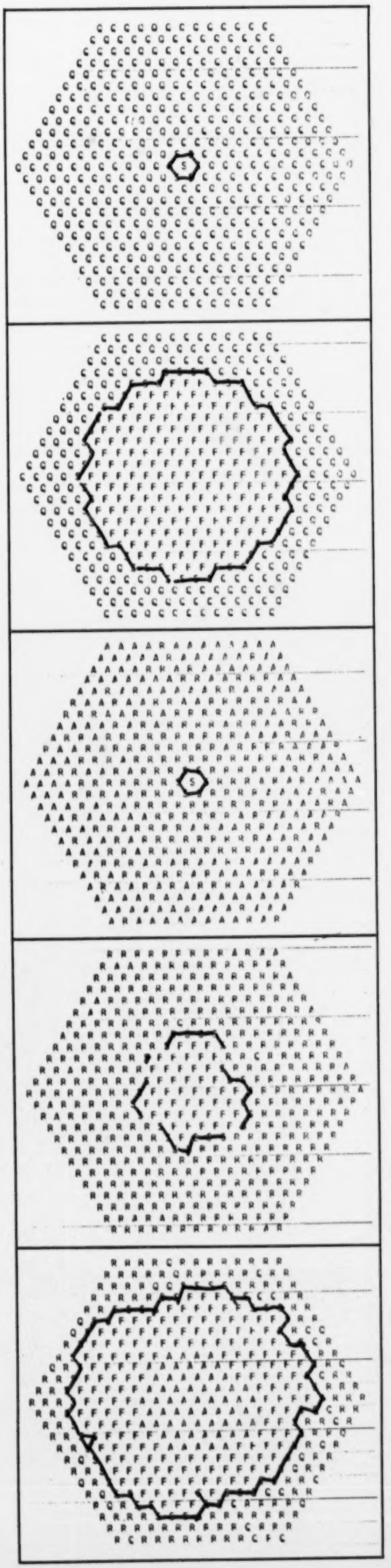








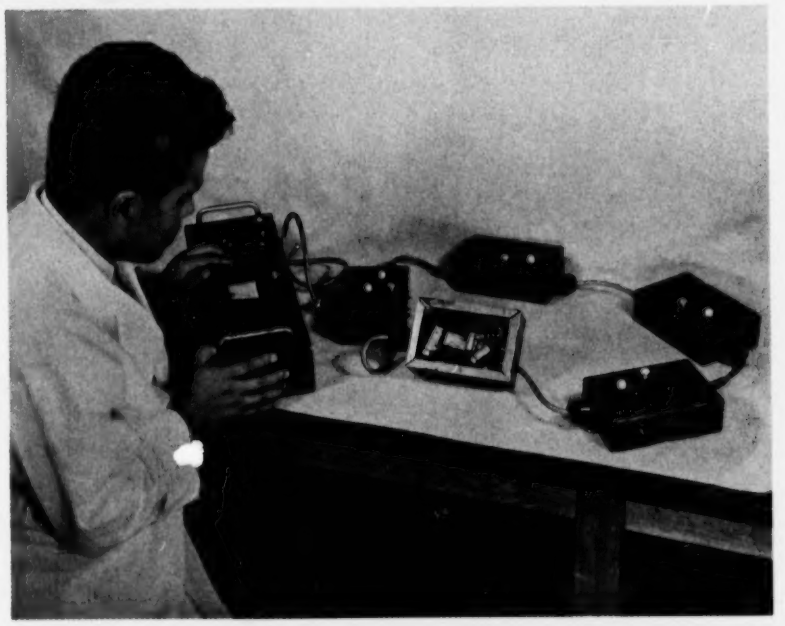
Elements for ARCH:GRAPHIC sequence at left include an octahedron, a stick figure, and a stretched cube, as shown in frame 1. In frame 2, Prof. Borkin uses these elements to produce a top view of an assembly of sixteen octahedrons and one stretched cube to form a module. Frame 3 shows an assembly of four modules also seen from above. The following sequence of frames shows how the structure, or octet truss, would look to an observer as he approaches, walks around, and enters. Above: *Gerald Rolfsen, Instructor and graduate student, computerized a spatial study of a custom home he was asked to design. Computer-generated drawings made it possible to visualize three-dimensional aspects of the design without building a real model.* Right: *Perspective drawings of a sofa designed and built by Dale Bryant represent views computer-drawn sequentially from a path around the sofa during the design stage. The finished sofa is shown in the photograph.*



FROM HEART TO MODEL CIRCUS

TO GRAPHICS

An individual cell in the heart can be in any one of five states: quiescent, receiving a stimulus, firing, absolute refractory, and relative refractory. In a normally functioning heart, all cells are in unison as they pass from one state to another. Fibrillation is a condition of heart muscle in which this unison is lost. During fibrillation, cellular activity is disorganized, and the tissue loses its ability to contract. Ventricular fibrillation, for example, which keeps the thick-walled pumping chambers from functioning, is the immediate cause of about half the world's deaths: those following poisoning, electrocution, freshwater drowning, and heart attacks. Medical scientists are attempting to learn what characteristics of an individual cell they can change with drugs to control fibrillation.



Electronic model of heart circuits, demonstrated by Dr. Yanagita, includes power supply and five excitable boxes. Unit two has been turned to display internal construction. When Dr. Swain and Dr. Flanigan prepared a program to simulate this model graphically, the type-character printouts looked like the adjacent frames. Right: *To better visualize the firing, Swain and Flanigan then prepared the Cardiac Network Simulation Series, which shows a sequence of states after cells have been stimulated in their relative refractory period as photographed from the terminal tube. Characters are translated in the accompany chart.*

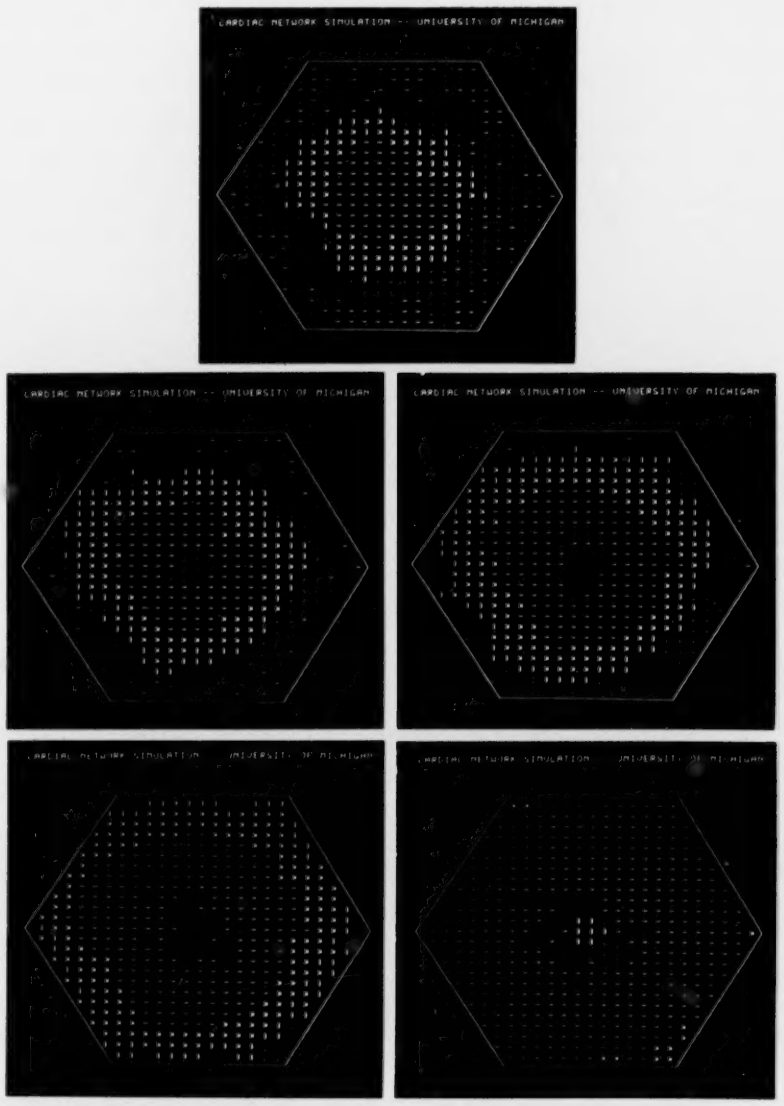
Dr. Henry H. Swain, Professor of Pharmacology, has conducted research sponsored by the National Institutes of Health on the development of drugs to control abnormal rhythm of the heart. Beginning with the analysis of hearts of experimental animals, Dr. Swain and Dr. Tomoji Yanagita constructed a functioning electronic model to replicate both normal heart rhythm and fibrillation. They built the classical rules of fibrillation into what they called a circus-rhythm model, a model that consisted of a power supply and five boxes with excitable colored lights. Cells in a quiet state showed no light; stimulated cells flashed yellow; firing cells, white; absolute refractory, red; and relative refractory, green. In the process, however, Swain and Yanagita found that some of the presumed rules did not, in fact, cause the model to work as the heart worked. They reexamined the functioning of the heart, took apart the original model, changed the wiring, and resoldered the boxes. By making these changes, the doctors did, indeed, construct a model that behaved like heart cells. The fibrillating cells flashed like the lights in a pinball machine.

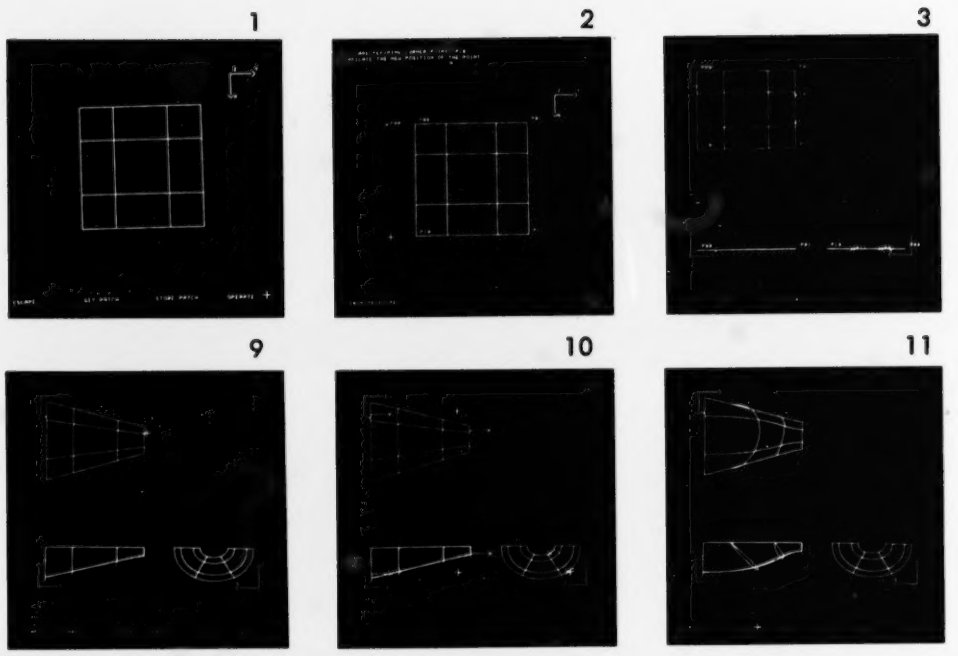
Next came the preparation of a computer program that behaved like the electronic model. Dr. Swain and Dr. Larry K. Flanigan, Associate Director of the Computing Center, prepared a computer simulation of the behavior of a network of cells which obeyed the rules and relationships specified by the model. In the computer printout, initial letters represented the five heart cell states. The activity grew scrambled and random during fibrillation. Once irregular patterns were set up, they continued. Although the printout sheets made fibrillation patterns explicit, Swain and his associates believed they could gain more insight into the fibrillation process by seeing it on the CRT.

On the face of the tube, the states are represented by line-dot coding (see chart). Frames change every fifteen seconds. While the regular movement or rhythm does not seem dramatic, the self-perpetuating whirlpool activity produced when a regular pattern is speeded up or interrupted seems to duplicate swirling heart-cell activity. "It is an intelligible way to handle a great deal of information," says Swain, "and as an experimental tool, it sends us back to the animal laboratory and tells us where to look, and which questions, of the million or so possible, are worth asking." Although Swain plans to make a graphics film of cardiac network simulation for instructional use, he believes that graphic presentations of fibrillation can provide researchers with unparalleled insight into what a drug must do to stop fibrillation.

CODING: 5 STATES OF HEART MUSCLE CELLS

State of Heart Cell	Boxes Blink	Typeprint	CRT Symbol
1. Quiescent	no light at all	Q	blank
2. Stimulated	yellow light	S	| vertical line
3. Firing (responded to stimulation)	white light	F	x times sign
4. Absolute Refractory Period (period following firing when cell cannot fire again; about 1/10 second in real heart)	red light	A	– horizontal line
5. Relative Refractory Period	green light	R	· dot





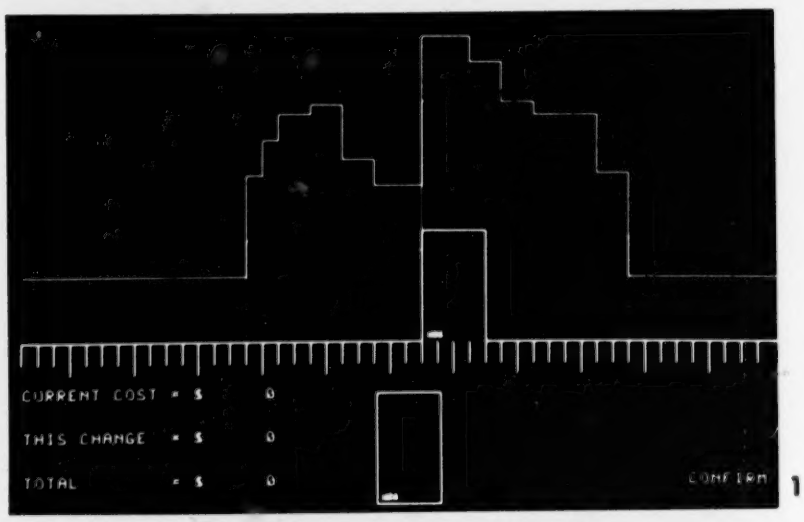
FREE-FORM SURFACES AND TIME-COST SCHEDULES

Although General Motors and other companies began exploring computerized design in the early 1950's, industry did not begin to take advantage of the design potential of the computer until the middle 1960's. In 1965, a book entitled *A Revolution in Design* by R. A. Siders and his Harvard research team demonstrated the potential impact of graphics on industry. Some of the most exciting advances in graphics have come from companies such as Boeing and Lockheed-Georgia, which use graphics to design and test aircraft parts and controls, and simulate pilot behavior. There remains, however, the challenge of reducing the complicated mathematical restrictions placed on a designer or engineer, and making graphics a more convenient tool for industrial design.

One aspect of this problem has interested industrial engineers at the University: the rapid manipulation of free-form surfaces. Car builders, naval architects, airplane designers, and others would benefit if shapes could be designed numerically to start with, permitting computation of their properties and eventual carving of the shape or shape-producing dies by numerically controlled machines. For researchers into the nature of surface mathematics, the graphics terminal seemed an excellent tool for displaying, manipulating, and testing the shapes quickly. The surfaces, in turn, seemed useful for investigating the nature of man-machine interaction. With problems of this type in mind and support from the Department of Defense, Bertram Herzog, Professor of Industrial Engineering, and Giorgio Valle, visiting Research Engineer, began their work on the interactive control of surface patches.

Herzog and Valle chose mathematical formulations that would allow the designer maximum freedom of choice in working with surfaces. Using the high-speed digital display terminal connected by a voice-grade telephone service to the computer, they attempted to work out a display system that would allow a user to "try and see," backtrack if results were not satisfactory, and eventually produce a numerically described shape or part. The system consists of a

Interactive graphics is demonstrated in this sequence of Dr. Bertram Herzog's patch manipulation photographed from the CRT at the Ouimet Building terminal. Frame 1 shows a standard square patch with axes indicated at top right. In frame 2, the label from the teletype asks for the next step and allows numeric specification of points for more precision. The following frames describe modifications made at the terminal with the light pen and keyboard. Notice the options available at the lower edge of each frame. By frame 8, the modified patch is displayed in orthographic view. Frame 16 shows that the patch obtained from the original square has been modified, rotated, and displayed. Right: *Graphs photographed from the CRT show (1) non-demand for power for a public electric utility with one component tentatively placed; (2) the symbol menu showing seven components of a public electric utility with schedule ready to be selected for placing on non-demand graph*



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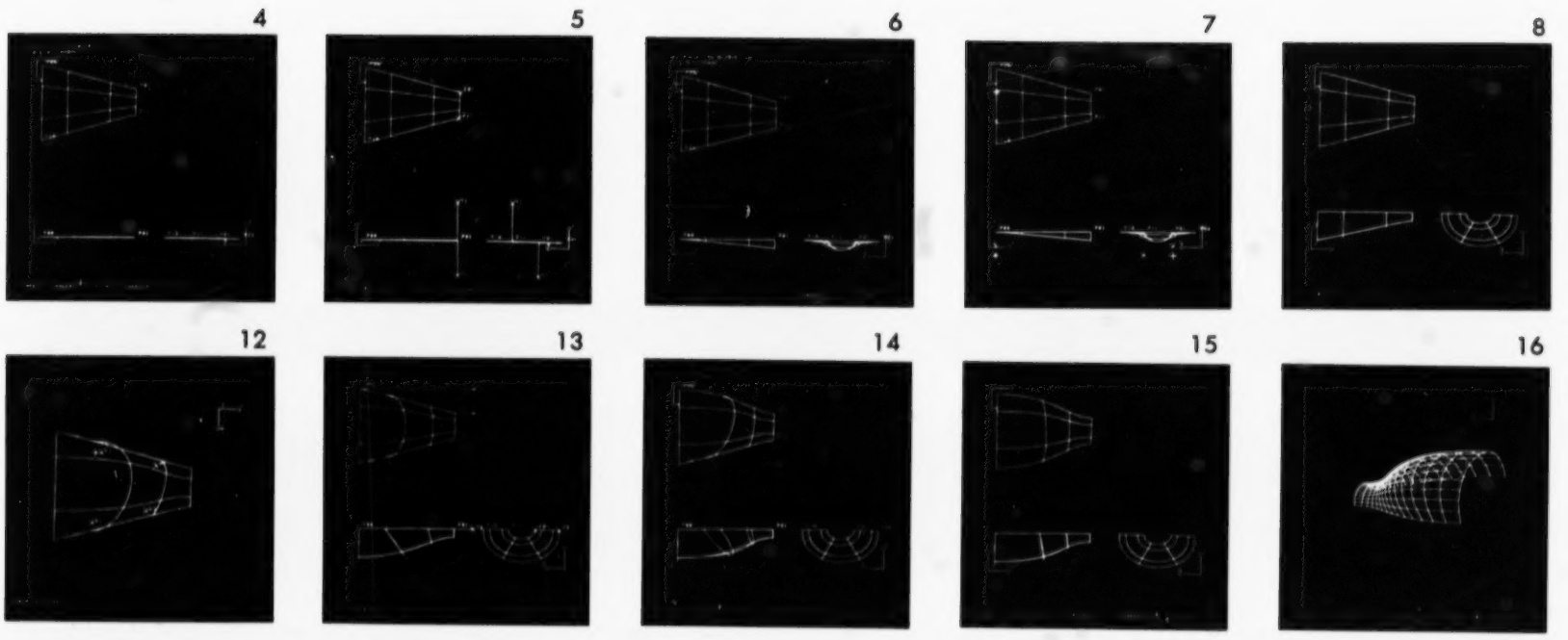
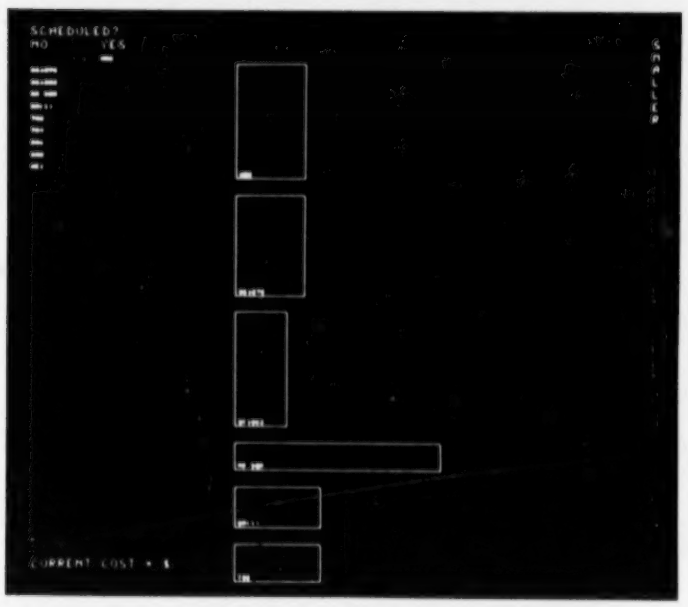
maintenance time; (3) the completed maintenance schedule of public electric utilities.



library of reference patches that the designer can call to the screen as starting points in any design sequence. Currently these include the square, hemisphere, a section of a torus, and other user-defined surfaces in the user's library. The user can operate on a patch in a variety of ways. Since the system consists of a collection of essentially independent subroutines, each one implementing a basic action, a user need only point at a list of commands to select the operation he wishes. Some of the available commands refer to means of modifying the patch by twisting, changing end points, or rotating the view to allow a three-dimensional look at the surface. The user may draw with the stylus on the Grafacon and see the drawing flashed on the CRT; he may move points on the face of the tube with a light pen; he may request storage of certain pictures for future retrieval.

Another application of graphics to industry was worked out by George Miller, a graduate student in industrial engineering. He investigated a problem that the industrial engineer faces when he schedules various components of a utility network for repair and maintenance. Miller describes a graph of the non-demand (or lack of demand) for power from a public electric utility on the CRT. On the vertical axis, the graph shows the power contribution in megawatts of power; on the horizontal axis it shows the number of weeks duration of the power contribution. The rectangle just below the graph represents one of the components. Its height indicates the power contribution of that component, and its width is the number of weeks of downtime required for the component's repair and maintenance. By using the symbol menu of various components, a user sitting before the CRT can try out various combinations of components for scheduling—this one for the third week in July, that for the fourth week in August—and learn the dollar penalty involved for each of the arrangements. The flexibility of manipulation plus the instantaneous time and cost calculations produced by the central computer suggest a wide range of uses of interactive graphics in industry, business, and management.



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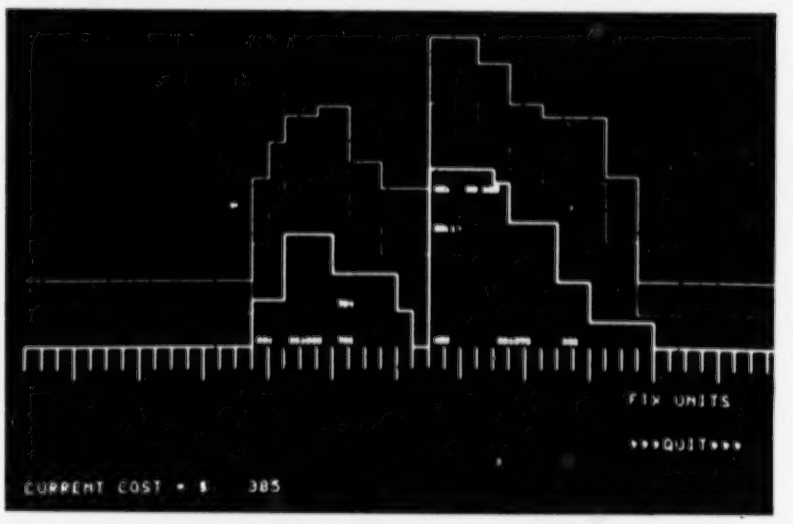
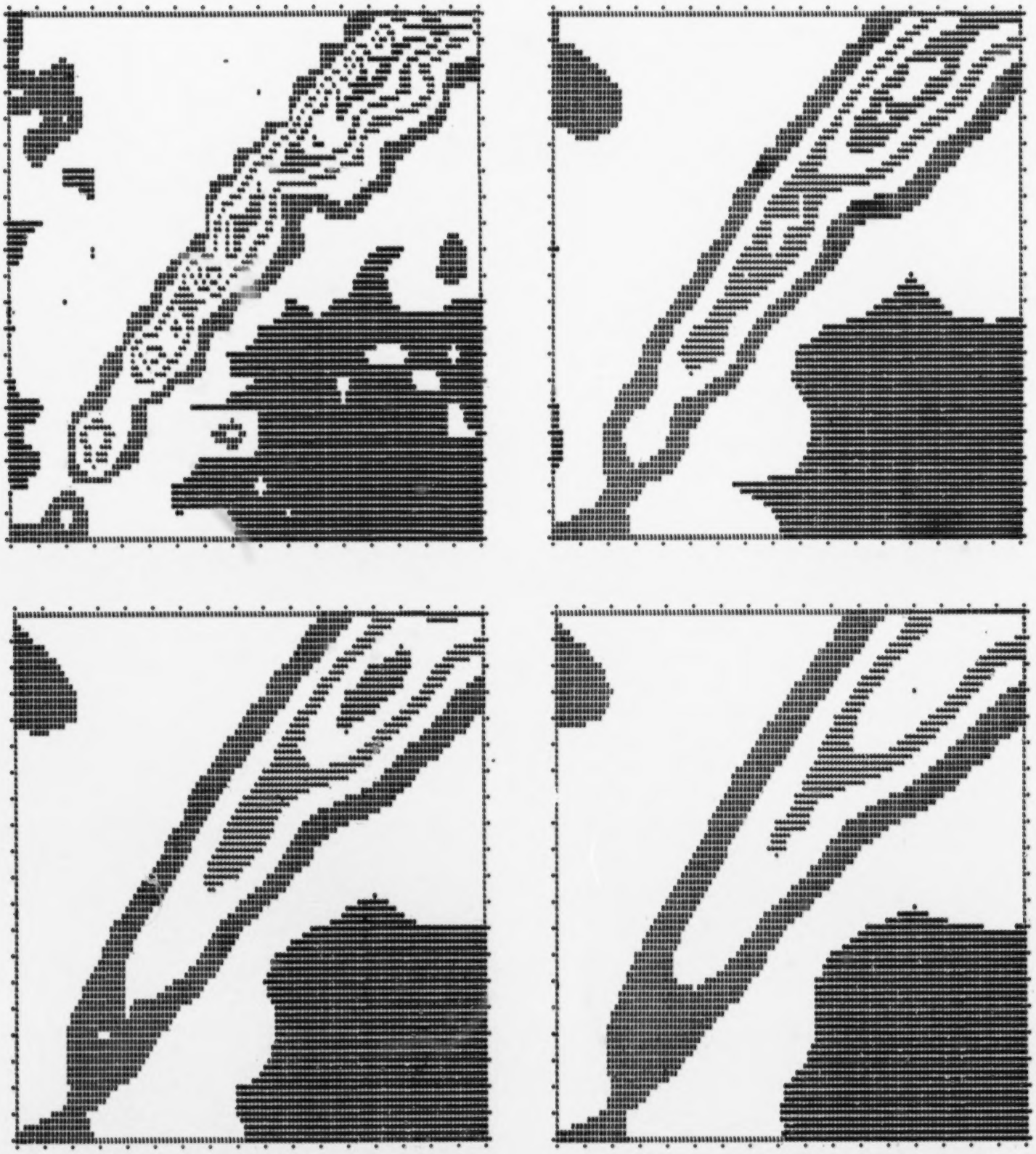


3

COMPUTERS AS AUTOMATIC DRAFTSMEN AND PICTURES PROCESSORS

–Mapping by Computer



Computerized map smoothing is a common way to clarify or simplify data. This display shows how maps composed of type-symbols can be smoothed to portray generalized elevations of the Akwapim-Togo mountain range in eastern Ghana.

Traditionally, geographers have made maps as a way of presenting and storing three-dimensional information in two-dimensional form; depth dimensions were often represented by coding, and time was conveyed only by a series of maps. In the past decade, however, cartography has undergone a variety of changes, improving depth and time representation and stimulating a new range of cartographic activities, among them picture processing and urban analysis. Each of these changes is related to computer graphics.

As an automatic draftsman, the computer can take a large quantity of data, produce a picture on a printer, on a mechanical drafting machine, or on a cathode-ray tube, and perform operations on that picture. It can be programmed to smooth the data presented in the map for clarity, to present maps in stereopairs that give depth dimension when viewed with glasses, or to draw a series of maps on the CRT that can be filmed and shown as a time-map.

Cartographers in the Geography Department have used the computer as a labor-saving, accurate tool for presenting geographic information in half a dozen different ways. The most recent innovation has been a computer movie simulating population growth in the Detroit region, with particular emphasis on the geographic distribution of this growth. Using a fairly complex mathematical model for processing population input into map form, Waldo Tobler, Professor of Geography, produced an experimental film covering the period from 1910 through 2000. The computer mapped the population distribution for every 0.05 year on the CRT using Richard Phillips's movie-making program. As an instructional tool, the film provides insight into the dynamics of urban growth; it also displays the predictive possibilities of computer-generated maps. Geographers as well as urban planners, for example, hope to extrapolate what effects a highway or shopping center may have on an area in five or fifty years by reducing enormous amounts of computerized data to easily readable maps. Geographers are also beginning to analyze the geographical diffusion of ideas with computer-drawn maps.

Tobler and others are now directing their attention to computerized picture processing. How does one feed a picture into a computer and come out with data, or put an aerial photograph of Ann Arbor into the computer and produce a map of dwelling units? Although processing pictorial information by computer has received a good deal of attention over the past fifteen years as a branch of computer technology, use by geographers and urban planners has been more recent.

As Tobler wrote recently, "One of the most important implications of automated methods in cartography is that they disrupt the traditional attitudes and force a reexamination of many of the conventional cartographic procedures. This should lead to many changes. The computer era is just beginning, and one wonders what maps of the twenty-second century will look like."

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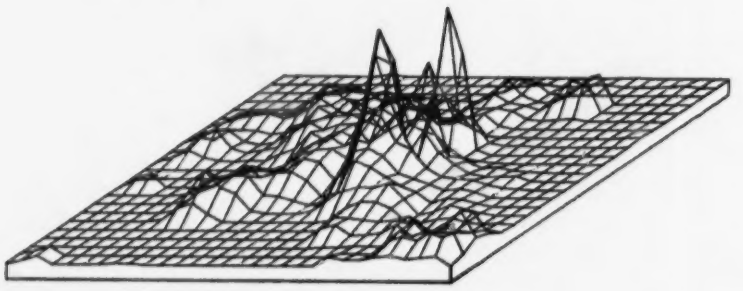
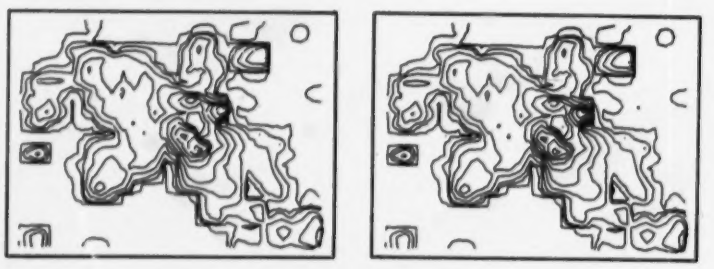
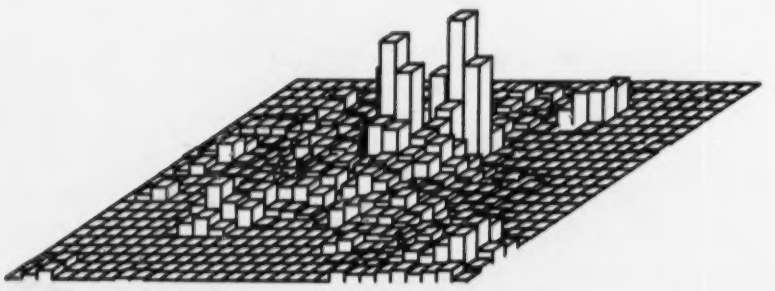
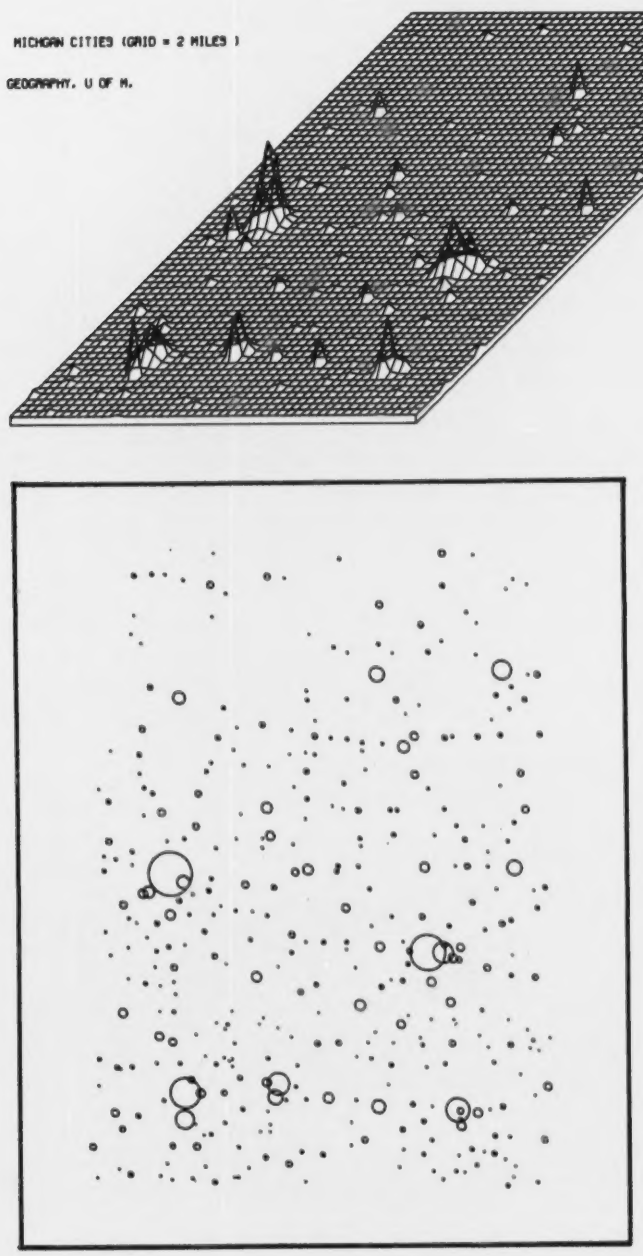






Right: *CalComp plotter draws three maps representing population density of Ann Arbor. Top figure is a block diagram with peaks representing population density. Middle diagram is a stereo-pair of computer-generated contour curves meant to be put in focus with stereo glasses. At the bottom is a three-dimensional histogram plot. These diagrams were developed by Frank Rens, formerly of the Geography Department, and Dr. Waldo Tobler, and are reproduced here through the courtesy of* Photogrammetric Engineering *magazine.*

Mapping by Computer *(continued)*



In the map pair on the left, Dr. Tobler illustrates two ways of presenting the population of some Michigan cities. In the grid map, each square equals two miles per side, and height is proportionate to population; circles represent the same information in the map below. Largest cities presented, left to right, are (lower row) Kalamazoo, Battle Creek, and Jackson; (upper row) Grand Rapids, Lansing, and East Lansing. The maps at the right, developed by Donald Deskins, Lecturer in Geography, show the concentration of the Detroit Negro population. In upper map, density is imposed on a hand-drawn base map with dot clusters. The totally computer-drawn lower map shows layers of density.

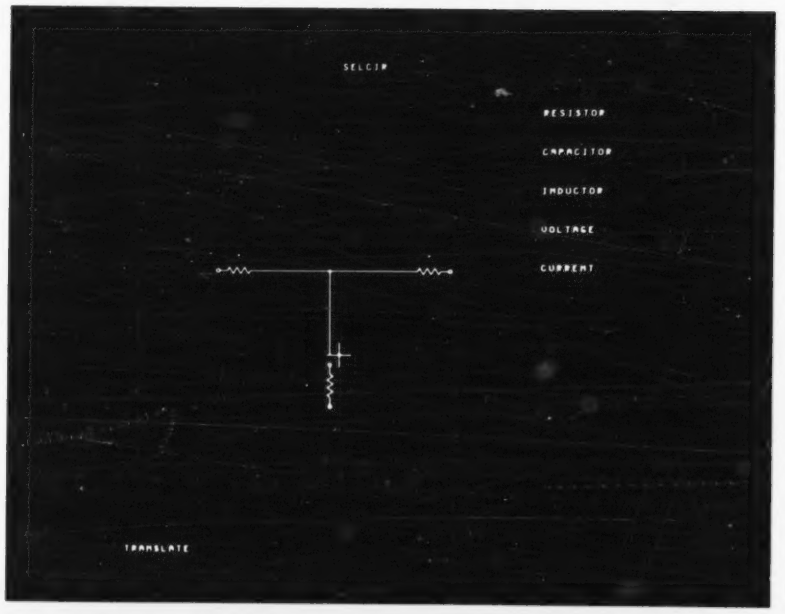
COMPUTER-AIDED DESIGN WITH SELCIR AND SELMA

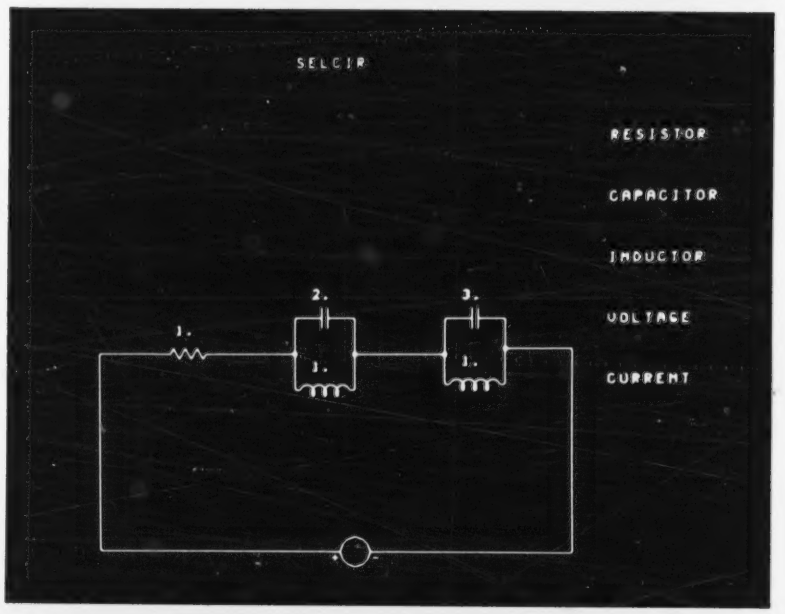
To analyze systems for a family toaster or an Apollo spaceship, engineers draw pictures and calculate the interactions of network components. They want to analyze networks to learn how the components interact and make changes that will streamline operations. For many years, electrical engineers have used computers to calculate and produce numerical results, but only recently has it become possible for them to avoid the time-consuming punchcard preparation and draw their network diagrams on the CRT screen for experimentation and instant solution. Now they can erase errors by a stroke of the light pen, turn a component 90° with a simple gesture, and see graphical results on the CRT within seconds.

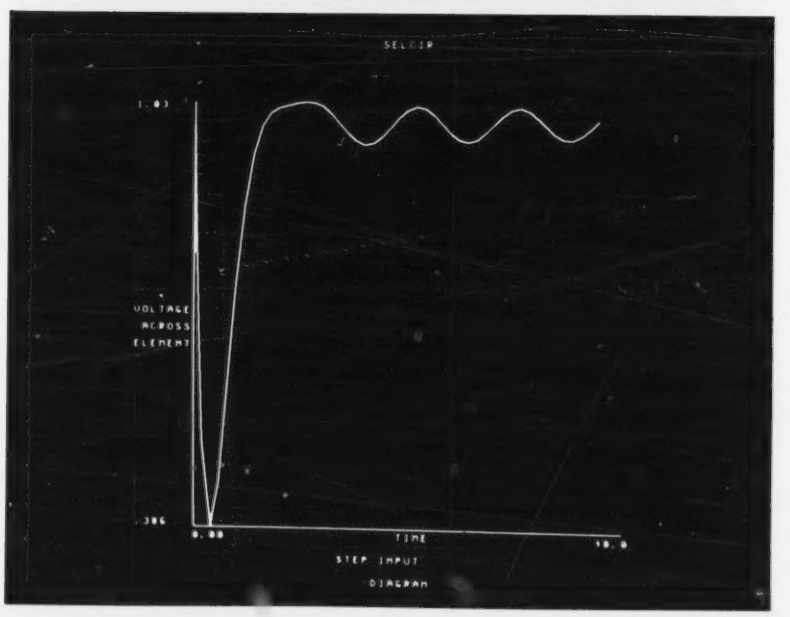
Research for probing electrical circuits and queueing networks was initiated at the University by Keki B. Irani, Professor of Computer Information and Control Engineering, Electrical Engineering, and a group of his colleagues and graduate students. Irani's group wrote a basic program for the DEC 339 computer located in the Systems Engineering Laboratory and called it the SEL Executive System. SEL Executive System is to the DEC 339 what the MTS is to the central computer at the Computing Center. This system provides common services to the application programs. Two main application programs written by Irani's group are SELMA, written by James Jackson for the queueing networks, and SELCIR, written by James Blinn for the circuit networks.

James Jackson, Research Assistant in Electrical Engineering, completed the SEL Executive System in 1968 and a conversational system for graphical specification of Markovian queueing networks in 1969 under a Department of Defense contract. SELMA (the Systems Engineering Laboratory Markovian Analyzer) is actually a set of programs designed to provide graphic manipulation for the Queue Analyzer System (QAS) program in the central computer. Terminal equipment at the Systems Engineering Laboratory can handle all SELMA operations except mistake-finding and final solution. Mistakes and solutions are managed at the Computing Center under QAS, then pre-

(continued on next page)







SELCIR is a circuit-drawing system that enables users to build circuits from basic components. The first frame in this series shows a circuit being drawn; the second shows a completed circuit; and the third shows a graph produced by the central computer showing the results of the analysis of this circuit.

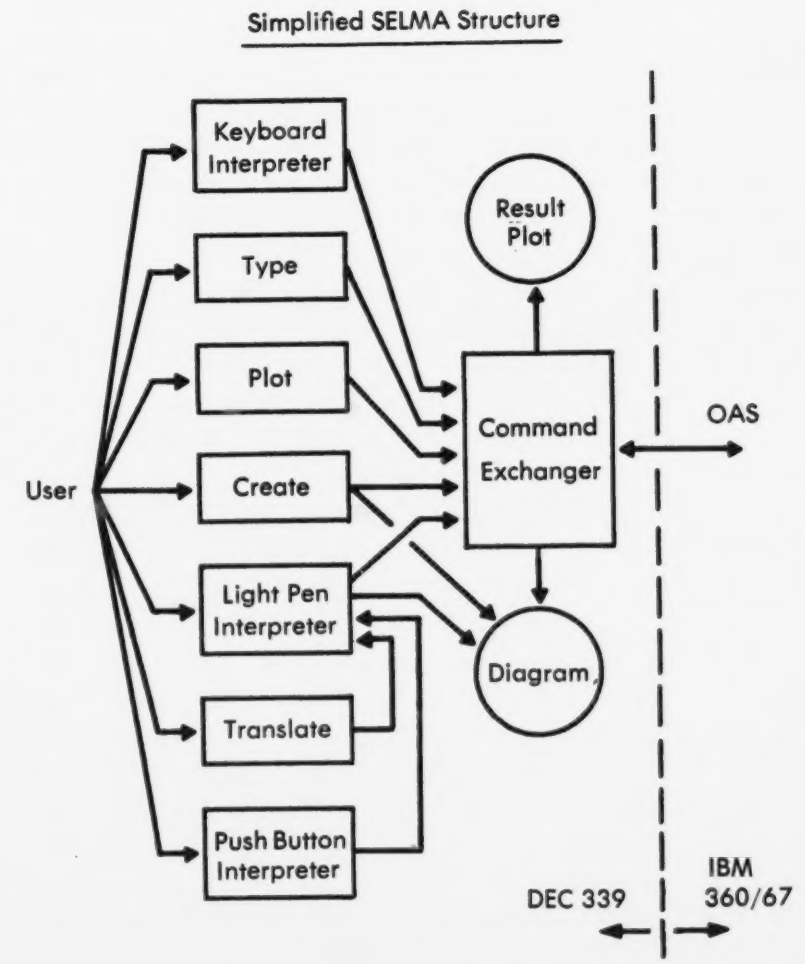
Computer Design with SELCIR and SELMA *(continued)*

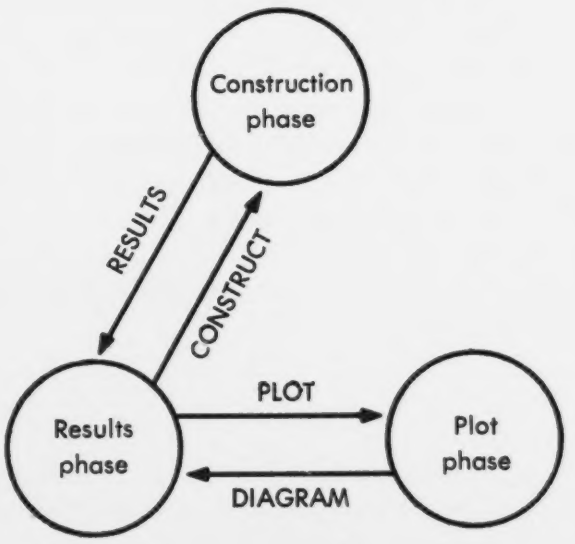
sented on the terminal display tube. SELMA allows a user to build a queueing network from basic elements with input and output ports. The program responds to the motion of the light pen. To draw, the user simply aims the light pen at the desired object, positions it, and makes gestures for connections, branches, or deletions. To assign parameter values, the user pushes buttons, thus placing numbers into the computer where they are needed for computation. To get results, the user may aim the light pen at the command word PLOT printed on the screen. If, at that point, an error is present in the drawing, e.g., a required connection is not made or a numerical value is incorrect, the computer displays information on the CRT indicating the position of the mistake. After the corrected diagram has been analyzed and the solution has been plotted, the user may indicate which section of a graph he wants expanded for closer analysis. The user may then recall the network diagram to the tube and modify it to obtain another solution, or he may store the diagram in the memory for future recall, modification, or recomputation. In this way, SELMA allows a user to analyze the behavior of many types of queueing networks, whether they are grocery store lines or a computer time-sharing system.

SELCIR (Systems Engineering Laboratory Circuit Analyzer) was developed by James Blinn, Research Assistant. SELCIR is a circuit-drawing system that enables the user to build circuits from basic components such as the resistor, capacitor, inductor, current generator, and voltage generator, and to assign values to network elements. All operations of SELCIR are handled at the Systems Engineering Laboratory except computation and analysis, which are conducted at the central computer. Results appear on the CRT in graph form.

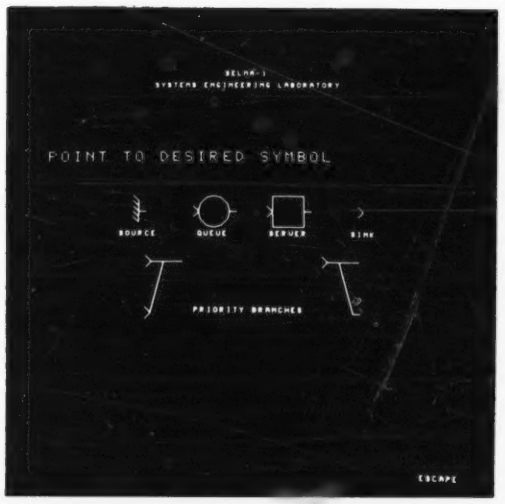
Both of these systems have experimental and instructional uses, giving engineering students opportunities to experiment at the CRT instead of at the drafting board. In addition, the DEC 339 terminal is used instructionally for computer-aided animation of physical phenomena. In the experimental stage is a program that displays physical simulation of the solar system showing how initial velocity, mass, and distance relationships of the planets affect their motions. This program can also illustrate such phenomena as scattering of alpha particles off of atomic nuclei. Another program provides a dynamic picture of a proton moving back and forth in the nucleus of an atom.

Programs to allow users to control the DEC 339 from a FORTRAN program at the Computing Center are also being perfected. This activity is particularly appropriate since the display terminal at the Systems Engineering Laboratory in East Engineering can now be used by anyone with a valid Computing Center user number.





Phase Transitions



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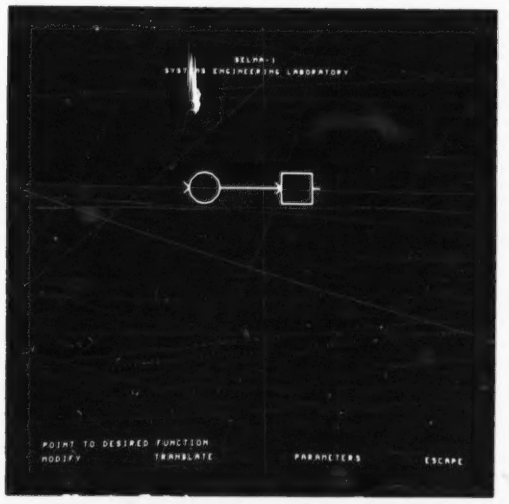

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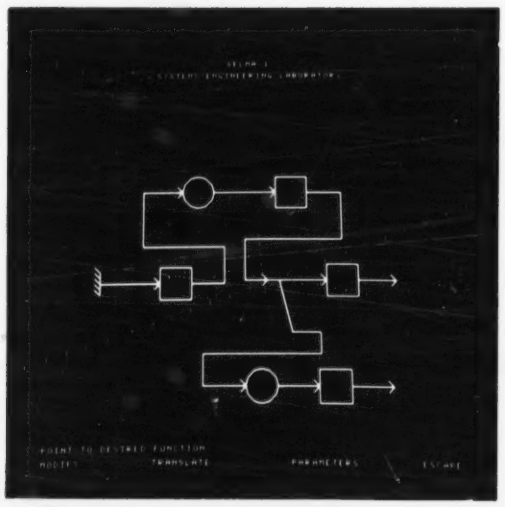

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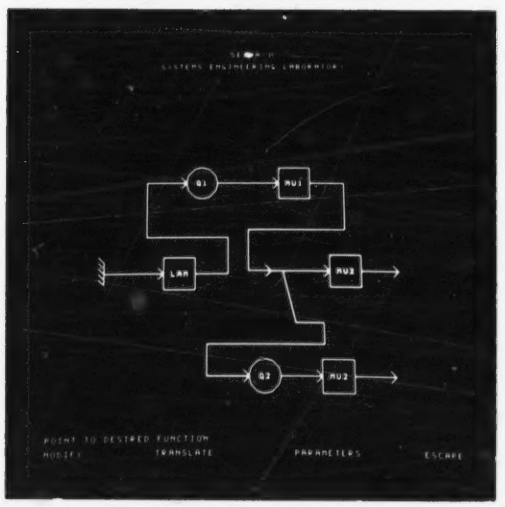

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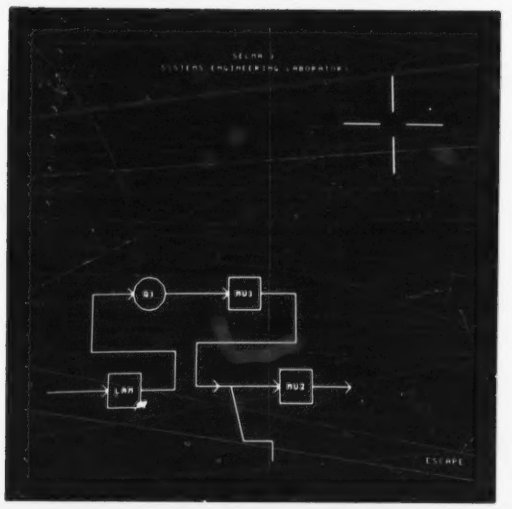

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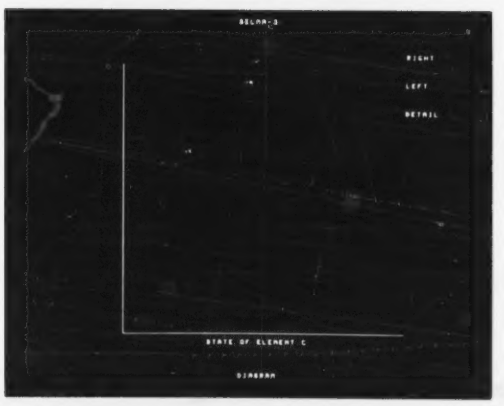
SELMA allows the user to operate with a vocabulary of symbols, experiment with specifications, and plot complex circuit operations in graph form. These pictures were photographed directly from the CRT. Operations in frames 1 through 5 were all conducted at the Systems Engineering Laboratory. Result plots for the models include the preparatory frame 6, i.e., before the graph is returned from the Queue Analyzer System program at the Computing Center, and frame 7, after the graph is returned. The user may also assign values to the graph or call for the expansion of any section.



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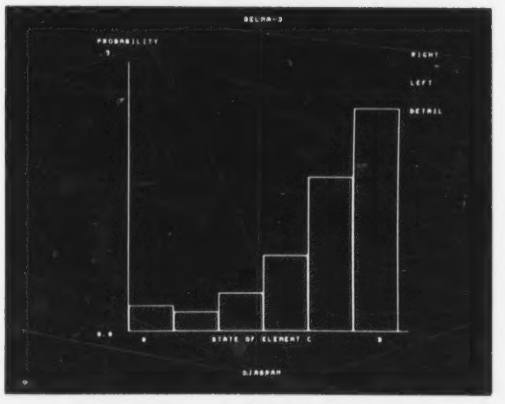

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SELECTED REFERENCES

For those who wish more technical information on topics mentioned in this article, research materials listed below are available from the respective authors. In addition, the June 1970 issue of *Scientific American* carries an authoritative article on the most recent breakthroughs in computer displays by Ivan Sutherland, who started it all in 1963 with *Sketchpad: A Man-Machine Graphical Communication System.* Further information on the University's Computing Center and its activities appears in the May 1964, June 1966, and November/December 1969 issues of *Research News*, available from the Office of Research Administration.

Borkin, H. J. and Oberdick, W. A., *ARCH:GRAPHIC*, Dept. of Architecture, Univ. of Mich., Ann Arbor, 1969.

Calahan, D. A., Gadol, S., Grapes, T. and Blinn, J., *Display Based Electrical Engineering Applications Programs*, Electrical Engineering, Univ. of Mich., Ann Arbor, Dec. 1969.

Chace, M. A. and Korybalski, M. E., "Computer Graphics in the Dynamic Analysis of Mechanical Networks," *Computer Graphics 70*, Proc. of an Intern. Symp. held at Brunel Univ., Uxbridge, Middlesex, England, 14–16 Apr. 1970.

Cocanower, A. B., *The DF Routines User's Guide*, Memo. 23, Concomp Project, Univ. of Mich., Ann Arbor, 1967.

"ConComp: Research in Conversational Use of Computers," F. Westervelt, Project Director, Final Report, ConComp Project, Univ. of Mich., Ann Arbor, 1970.

Flanigan, L. K. and Swain, H. H., "Computer Simulation of A-V Nodal Conduction," *Univ. of Mich. Med. Ctr. J.*, Ann Arbor, Vol. 33, Sept.–Oct. 1967.

Fronczak, E. N. "Digital Plotting System," Computing Center, Univ. of Mich., Ann Arbor, March 1967.

Geister, D. E. and Phillips, R. L., "On Line Graphical Data Reduction for Undergraduate Engineering Laboratories," presented, Conf. on Computers in Undergraduate Curricula, 16–18 June 1970, Univ. of Iowa, Iowa City.

Goodrich, S. D., *DRAWL User's Guide for the IBM 1130/2250*, ConComp Project, Univ. of Mich., Ann Arbor, Dec. 1969.

Herzog, B. and Shadko, F., *DRAWL-70 (Drawing Language)*, ConComp Project, Univ. of Mich., Ann Arbor, 1970.

Irani, K. B., Wallace, V. L. and Jackson, J. H., "Conversational Design of Stochastic Service Systems from a Graphic Terminal," Systems Engineering Laboratory, Univ. of Mich., Ann Arbor, 1970; also in *Computer Graphics 70*, Proc. of an Intern. Symp. held at Brunel Univ., Uxbridge, England, 14–16 Apr. 1970.

Jackson, J. H., "SELMA: A Conversational System for the Graphical Specification of Markovian Queueing Networks," Systems Engineering Laboratory, Univ. of Mich., Ann Arbor, Oct. 1969.

Levy, M. A., Pollack, H. N. and Pomeroy, P. W., "Motion Picture of the Seismicity of the Earth, 1961–1967," *Bull. Seismol. Soc. of Amer.*, Vol. 60, No. 3, June 1970.

Miller, G. and Wilson R. C., "A Computer-Aided Graphical Procedure for Scheduling Preventive Maintenance of Electric Power Generating Units," submitted for publication, *AIIE Trans.* (Amer. Inst. of Indus. Engin.), 1970.

Mills, D. L., *RAMP: A PDP-8 Multiprogramming System for Real-Time Device Control*, ConComp Project, Univ. of Mich., Ann Arbor, May 1967.

MTS Manual (several volumes), Computing Center, Univ. of Mich., Ann Arbor, 1970.

Phillips, R. L. and Geister, D. E., *Application of a Graphics Display Terminal to Engineering Laboratory Courses*, presented at the Eighth Meeting of UAIDE (Users of Automatic Information Display Equipment), 2–4 Nov. 1969, San Diego.

Phillips, R. L. and Geister, D. E., "Production of Computer-Animated Films from a Remote Storage Tube Terminal," presented, Conf. on Computers in Undergraduate Curricula, 16–18 June 1970, Univ. of Iowa, Iowa City.

Pollack, H. N., "A Numerical Model of the Grand Canyon," *Geology and Natural History of the Grand Canyon Region*, ed. D. L. Baars, Four Corners Geological Society, Guidebook to the Fifth Field Conf., 1969, pp. 61–62.

Pollack, H. N., Levy, M. A., Fountain, D. and Pomeroy, P. W., "Seismicity Movies of the Circum-Pacific Belt: Part 1. Large Magnitude Events, 1897–1964; Part 2. Magnitudes 4.5 and Greater, 1961–1967," *Program of General Scientific Assembly, International Association of Seismology and Physics of the Earth's Interior*, Madrid, Sept. 1969 (abstract). The film is 16-mm, silent, black and white, 250 feet long, and completely self-documented. Prints cost $30.00, including postage, from: Seismological Observatory, Dept. of Geology, Univ. of Mich., Ann Arbor, Mich. 48104.

Pollack, H. N. and Pomeroy, P. W., "Motion Picture Display of Time-Varying Geophysical Data," *Program of Meeting: Sixth Upper Mantle Committee Symposium on Geophysical Theory and Computers*, Copenhagen, Aug. 1969 (abstract).

Swain, H. H. and Yanagita, T., "A Model Circus," *Univ. of Mich. Med. Bull.*, Ann Arbor, Vol. 29, Nov.–Dec. 1963.

Tobler, W. R. "A Computer Movie Simulating Urban Growth in the Detroit Region," Dept. of Geography, Univ. of Mich., Ann Arbor; prep. for the Intern. Geographical Union, Commission on Quant. Geog., Aug. 1969 meeting.

Valle, G. and Herzog, B., "Interactive Control of Surface Patches from a Remote Graphics Terminal," *Computer Graphics 70*, Proc. of an Intern. Symp. held at Brunel Univ., Uxbridge, England, 14–16 Apr. 1970.

The *Research News,* published monthly by the Office of Research Administration of The University of Michigan, attempts to serve interested readers both inside and outside the academic community by reflecting the diverse forms of modern university research. Some issues survey a general area of research; some are focused on organizational units; others describe long-range undertakings; and still others provide a basic introduction to some subject. Throughout the diversity of subject and approach, however, there is a consistent attempt to interpret matters of general interest in terms of particular efforts, and to give some idea of the forms in which these efforts are expressed at one large university. Current issues of the *Research News* are distributed without charge. A complete file, dating from 1952, can be purchased on microfilm from University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan 48103. Correspondence concerning the *Research News* should be addressed to the Editorial Office, Office of Research Administration, The University of Michigan, Ann Arbor, Michigan 48105.

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